

PRACTICAL ENERGY AUDIT MANUAL

Industrial Furnaces

Prepared by



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for

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PREFACE

Energy inputs - both electrical and fuel - are an essential part of manufacturing process, and expenditure on these inputs often accounts for a significant share of the manufacturing cost. This is compounded by the fact that the cost of energy is constantly escalating and will continue to rise.

Any saving in energy costs directly adds to the operating profits of the company. It probably requires less effort to improve profits through energy savings than by - reducing labour cost, increasing sales, increasing prices, reducing distribution costs, etc.

The main purpose of an energy audit is to systematically identify practical and feasible opportunities for saving all forms of energy in a plant and realise the benefit of cost reduction. Experience shows that as much as 10-15 percent of energy could be saved without any need of large investments, through energy audits.

The main objective of this manual is to familiarise the plant personnel in the techniques, methodology and approach to in-house energy audits. Since energy conservation is essentially a continuous exercise, it is inevitable that the plant personnel are able to regularly monitor trends in energy consumption and initiate remedial measures to improve energy efficiency.

Section 1 : Introduction

Energy management is a disciplined activity, for the more efficient use of energy without lowering production levels, product quality, safety and environmental standards.

The principle underlying all energy management must be cost effectiveness; energy conservation should and, is restricted to the extent that it can be justified in normal commercial and financial terms. The entire concept, therefore, requires both technical and financial evaluations, along with other considerations such as the human resources, the environmental implications and of course, the ever-present attitude of "no-change" which very often needs a nudge to "change".

Energy management requires a logical and comprehensive management approach. Experience shows that energy savings are only significant and long lasting, when they are achieved as part of a plant energy management programme. A systematic and structured approach is required to identify and realise the full potential of savings that can be achieved, mainly through low-cost measures. The energy management programme can be made "self-financing" - with the savings of the low-cost short term measures being utilised for the implementation of more capital-intensive retrofits. The basis of such a programme has to be a comprehensive and professional energy audit, in order to assess the current consumption pattern and identify potential opportunities to conserve energy, given the existing framework and infrastructure of the industry.

Specific energy consumption – the amount of energy consumed per unit of output – varies widely depending on the product in question, the type of manufacturing process, type of fuel, age of equipment, size of the plant and operating practices. Industrial furnaces of any kind are highly energy-intensive and therefore, have been taken up for a specific study in this document.

Four broad kinds of industrial fired furnaces are covered in this document – fuel fired furnaces, resistance furnaces, electric arc furnaces and induction furnaces. Apart from fuel handling procedures, the efficiency of operation, waste heat recovery and insulation are also discussed, with relevant live case studies to substantiate the conservation potential.

With the opening up of the industrial growth policy and economic reforms, a higher growth rate in this area is feasible, if state-of-art technologies are adopted in the fields of energy consumption, pollution control, thermal efficiency, raw

material and utilities consumption. The opportunities for saving energy and thus improving profits could be made feasible by a systematic evaluation of the technological gaps, in order to improve the performance and reduce the energy consumption.

This aspect, therefore, forms the basis of this document, with the conservation opportunities being restricted to the feasible and practical ones only.

Section 2 : Types of Industrial Furnaces

Industrial furnaces have been prevalent in India for about 50 years as a part of the manufacturing sector, and for over a century as part of the end user operations. However, the furnaces still do operate on outside technology for specialised and high capacity furnaces.

The furnaces in India are mostly medium sized, compared to developed countries, with the maximum size of the electric arc furnace being about 80 tonnes, while the maximum capacity of the induction furnace is around 20 tonnes.

2.1 Classification of Furnaces

Based on the method of generating heat, furnaces are classified as Combustion or Electric Furnaces. Depending on the type of combustion, the former are broadly classified as Oil Fired, Coal Fired or Gas Fired. The Electric Furnaces can be Resistance, Induction Melting or Electric Arc Furnaces.

Another classification, based on the handling of material as it passes through the furnace, divides furnaces as Intermittent or Batch and Continuous Furnaces. In the former, the stock to be heated is laid in a particular position and remains there until it is heated. The stock is then removed from the same door through which it entered. In the continuous type, the stock moves while it is being heated, since it enters through one door and leaves through another.

Depending upon the position and movement of the products of combustion vis-à-vis flame position, furnaces are classified as:

Under Fired: The flame is produced under the hearth and the products of combustion rise up into the heating chamber.

Side-Fired: The flame is produced in a combustion chamber at one side of the heating chamber and the products of combustion pass over a bridge wall into the heating chamber.

Over-Fired: The flame is developed in a space above the heating chamber and the products of combustion pour into it through a perforated arch.

For certain processes, direct contact of the products of combustion with the stock

would imply endangering the product quality. In such a case, the stock is enclosed in a muffle, which in turn, is heated by the products of combustion. Such furnaces are called 'Muffle Furnaces'. If protection against high temperature is the objective than protection from furnace atmosphere, the roof of the muffle is omitted and in such a case, the furnace is called 'Semi-muffle Furnace'.

Furnaces can also be classified based on the use of furnace and the shape of the material to be heated. Furnaces used for heating large ingots in a vertical position are called 'Soaking Pits' or 'Ingot-Heating Furnaces'. Furnaces, in which the end of a bar of any shape is heated for forging or welding, are called 'Forge Furnaces'. If the ends of many bars are to be heated at one time, the furnace is provided with a horizontal slot for admitting the bars and such furnaces are called 'Drop-Forge furnaces'.

Some furnaces derive their name from the component being heated such as 'Plate Furnaces', 'Angle Furnaces', 'Rivet Furnaces', and so on. In 'Carburising Furnaces', the material to be case-hardened is either packed in carburising powder and heated in pots or is heated in a carburising atmosphere.

2.2 Features of a Typical Furnace

In most furnaces, the stock rests on a hearth. The heating chamber is surrounded by the sidewalls and a roof, usually in the shape of an arch. The highest point of the arch is called the crown. The most common material for furnace construction is firebrick, made of fire clay. In order to reduce heat losses, furnaces are built of insulating firebrick or covered with an insulating material. Firebricks are laid with a thin layer of mortar between them. Other materials used for walls and roofs of furnaces are plastic fire-clay rammed into place and hydraulic heat-resisting concrete. The refractory bricks and their properties are discussed in detail in Appendix 1.

Insulation of a furnace forms an important area, which could meaningfully contribute to reduction of heat losses, thus increasing thermal efficiency. In light of this, proper selection, application and maintenance of insulating materials are very critical. Insulation and properties of insulating materials are more fully discussed in Appendix 2 while Appendix 3 discusses the ceramic fibre insulation.

2.3 Fuel Fired Furnaces

The most common fuels in a furnace are various types of oil, gas and coal. A required quantity of air is necessary to supply the required amount of oxygen for combustion. Approximate ignition temperatures for common fuels are given in Table 2.1.

Table 2.1 : Ignition Temperatures for Common Fuels

Fuel	Ignition Temperatures °C
Furnace Oil	750
Bituminous Coal	400
Anthracite Coal	500
Rice Husk	500

Sufficient time must be available for combustion to be complete. Turbulent mixing of fuel and air is important to ensure complete combustion.

2.4 Resistance Furnaces

The design of resistance furnaces varies with the mode of heat transfer used in the furnace viz., radiation, convection or conduction. In the first group, resistors - metallic or non metallic, are arranged on some or all of the walls; the energy is transferred to the load mainly by radiation and in part by natural convection. A variation of this design comprises resistors embedded in the furnace wall, the latter transmitting heat to the charge by radiation. In the second group, resistors are separated entirely from the charge; an air or gas stream passes over the resistors, absorbs their heat, and transfers the heat to the charge. In the third group, heat is transferred to the charge by conduction from a liquid bath of lead, salt or oil, which in turn, is heated either by external resistor or by passing current through the bath. In the fourth group, material to be heated itself serves as the resistor. These furnaces are called direct resistance-heating furnaces.

- a) **Low and Medium Temperature Furnaces :** These furnaces are characterized by the use of nickel-base resistors. The applications of these furnaces are as follows:

Metals : Heating for hardening, carburising, annealing of steel and ferrous metals, providing malleability, normalising, general heat treatment, annealing and heating for forging or extruding of copper and its alloys, melting, annealing and age hardening of aluminum, magnesium and light alloys, melting lead, tin, zinc and similar metals, brazing and soldering ferrous and non-ferrous metals, vitreous enameling.

Ceramics and Glass: Glass lehrs, decorating kilns for China and earthenware.

Chemicals: Cracking of gases, coke production.

Resistors: Copper nickel alloys are used for low temperatures up to approximately 540° C. In some cases, nickel, nickel manganese, or nickel iron resistors are used for temperatures up to approximately 650° C. Alloys of nickel and chromium are generally used for resistor temperatures up to 1150° C or 1200° C.

- b) High Temperature Furnaces : This type of furnace may be used for forging and brazing of metals as well as for heat treatment of high alloy steels. It is also used for sintering of powdered metals and melting of metals in the medium temperature range. Firing and glazing operations for tile, whiteware and pottery, ferrites, titanates and steatites in the production of ceramics are conveniently carried out in high temperature furnaces. Production of fritte and melting of small batches of glass can be carried out successfully in the high temperature furnaces. The high temperature resistor furnace is also used in some electrochemical processes.
- c) Direct Resistance Heating : The material to be heated serves as the resistor. Current enters and leaves at or near the ends of the metallic bar. The contacting ends of the two electrodes are made of soft copper and are water cooled to allow uniform current through the metallic bars with irregular end shapes. Direct resistance heating of steel bars is limited to 1200°C and 6.5 cm² to avoid non-uniform heating between the outer and inner sections of the bar. This type of heating does not provide uniform temperature, if the cross section varies along the length of the bar.

2.5 Resistors

Non Metallic Resistors: Non-metallic high temperature resistors are made of sintered silicon carbide. Resistors consist of rods or tubes of length such as to extend through the furnace walls. The resistivity of the element is higher in the central heating part than in the two cold ends, which penetrate the walls, thus reducing heat generation in the walls and corresponding heat losses.

Metallic Resistors: Alloys of iron, chromium and aluminum have refractory properties and resistors have been developed so that they are suitable for industrial heating use. But these are quite brittle in cold state, especially after some period of high temperature operation.

2.6 Conveying Mechanisms for Resistance Furnaces

Conveying devices can be arranged in numerous ways to suit furnace requirements, but broadly classified into four groups. The first group never enters the furnace, the second remain permanently inside the furnace, the third includes devices that are brought into the furnace chamber for a short period only. Devices belonging to the fourth group remain inside the furnace as long as the charge remains.

When conveying mechanisms do not enter the furnace, part or the entire load is transported into the furnace pushed on a dummy prepared on a rack outside the furnace. This group includes walking beam, roller hearth, rotary hearth, rotary drum and conveyor belt furnaces.

Walking beam furnaces are advantageous both at low and high temperatures. They are desirable for low temperatures because of their simple design and at high temperatures, since their mechanically sensitive parts are protected against heat.

In roller hearth furnaces, the hearth is covered by a number of rollers, which carry the load. They have high heat losses.

Rotary hearth furnaces are economical in power consumption. The same operator can often load and unload the furnace, since the charging and discharging doors are close together.

In mechanisms where loading devices remain inside the furnace for a short time, the main disadvantage is that a lot of furnace space is lost due to the charging machine and therefore the heat losses increase.

Mechanisms, where loading devices remain inside the furnace as long as the charge, include conveyors, car bottom furnaces and overhead trolleys. In the car bottom furnace, there is infiltration of cold air, which can be prevented by sand or similar sealing material.

2.7 Induction Furnaces

Induction furnaces are widely used in the foundry industry. Out of the two types of induction furnaces - core-less and channel - the former finds application in melting cum holding operations. These furnaces were traditionally designed to operate at frequencies of 50 Hz with a molten metal heel. Medium frequency furnaces operating between 150 and 1000 Hz, are posing a serious challenge to the mains frequency furnaces, because of their ability to operate without molten heels and their smaller size.

The working of induction furnaces is based on the principle of electromagnetic induction with the same concept as that of a transformer, but with a single turn, short-circuited secondary winding. The charge to be heated and melted forms the secondary, while the hollow water-cooled copper coils excited by AC supply form the primary.

In the core type (channel) furnaces, in order to maintain the electric path, there must always be sufficient molten metal in the furnace. This is called the molten heel.

In the coreless induction furnaces, the primary coils surround a refractory crucible in which the charge to be melted is put. The eddy currents induced by the primary winding generate heat in the charge. Since there is no core, a large current is required to overcome the reluctance between the coils and charge, and results in a very low power factor.

A laminated magnetic yoke surrounds the coil to provide a return path for the flux to prevent stray losses and improve power factor. The whole furnace is contained in a mechanically rigid structure and mounted so that it can be tilted for pouring. A schematic is shown in Fig. 2.1.

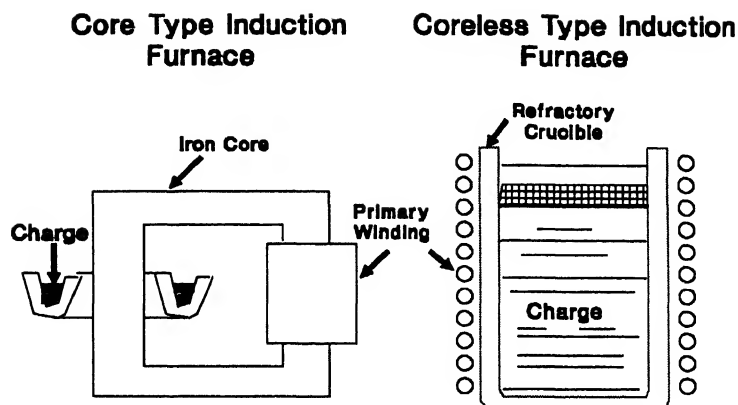


Fig. 2.1 : Schematic of Induction Furnace

Advantages of Using Induction Furnaces

- a) Reduced pollution due to gases and combustion products and noise levels as compared to other types of furnaces.
- b) Fast melting.
- c) Improved working conditions, as there are no excessive heat losses.
- d) Reduced metal loss due to oxidation.
- e) Automatic stirring due to eddy currents, though this may be undesirable under certain conditions.

Energy Efficiency in an Induction Furnace

The primary coils are connected to the AC power supply. The primary coils induce eddy current and hysteresis in magnetic material, before it reaches the Curie temperature in the charge. As a result, the charge is heated up and melts. The sensible and latent heat gains in the charge form the largest slice of the energy output. This includes energy required for maintaining the temperature of the molten metal.

A large current is required to generate the required heat. This causes large I^2R losses in the copper coils in the form of heat and is carried away by the cooling water flowing through the coils. Other losses include radiation and conduction through the walls, losses due to the roof of the furnace being open for charging, and heat in the slag.

2.8 Electric Arc Furnaces (EAFs)

EAFs consume nearly 1.5% of the total electricity consumption in the country and account for about 2.8% of the electricity consumed in the industrial sector. The EAF is mainly used for melting and refining of ferrous and non-ferrous metal. The average specific energy consumption for steel making by the EAF route is 700 - 750 kWh/ tonne liquid steel in India, almost double that of the developed countries such as USA, Germany and Japan.

An EAF broadly consists of a refractory-lined vessel in which the charge to be heated is placed. A refractory lined roof covers the vessel, with three electrodes mounted onto it. The electrodes are connected across the secondary of a step-down transformer with on-load voltage tap changing. The basic requirements of the electrical system are:

- i) Low electrode current
- ii) Arc stability
- iii) Over current protection
- iv) Isolation of the furnace from the supply during charging and metal tapping.

The electrodes can be lowered or raised with respect to the charge with the help of an electro-mechanical, hydraulic or pneumatic system.

The heat required for melting is supplied by the electric arc struck between the electrodes of the furnace and the scrap iron charge. The three electrodes are made of graphite rods supported on electrode arms. The electrode arms should be rigid enough to bear mechanical resonance frequencies and other dynamic forces acting on the arms. These forces are dependent on interaction of electrode current (I), length of parallel conductors (L) and distance between the conductors (D).

Graphite electrodes account for prime share in the cost of EAF operation. Introduction of water-cooled electrodes can reduce the electrode consumption by 30%, but this requires suitable modifications in the electrode arms, cooling water system and furnace area. Furnace operational delays and energy losses occur due to electrode breakage. Proper joining of electrodes can help reduce operating costs.

Replacement of refractory lining in the EAF forms the other major share of consumable cost. Though the replacement has drastically reduced with the use of water-cooled panels for the roof and sidewalls, the energy loss through these

panels may account for 25-32% of the total energy input. Most of the heat is picked up by the water above the slag line. The advantage of these panels is that they allow UHP (ultrahigh power) operation for longer periods, thereby reducing the melting cycle. But these panels suffer from a serious drawback of water leaking into the furnace.

Energy Balance in EAF

The balancing of energy inputs and outputs in an EAF is essential before suggesting any energy conservation measures. The first step would be to establish a material balance for the furnace, for which inputs include the charge, graphite electrodes, limestone or calcined lime, coke, oxygen and alloying constituents. Molten metal, slag and exhaust gases comprise the output. The next step in arriving at an energy balance would be to compute the heat gains and losses by way of sensible and latent heats and exothermic and endothermic reactions. A typical energy balance is shown in Table 2.2.

Table 2.2 : Energy Balance in an EAF

Particulars	Energy Consumption, %
Energy Inputs *	
Electrical power	76
Exothermic reaction like decarburisation,	20
Graphite electrode oxidation	04
Total	100
Energy Outputs	
Sensible heat in tapped metal	27
Sensible heat in molten metal	04
Sensible heat in slag	04
Sensible heat in refractories	06
Heat carried away by cooling water	25
Heat carried away by exhaust gases	24
Electrical losses in electrodes	05
Radiation and convection losses	03
Unaccounted losses	02
Total	100

* Oxy-fuel burners also supply energy, though not shown in this chart.

Section 3 : Energy Conservation Opportunities

This section deals with four types of furnaces, viz. the fuel fired, resistance, induction and electric arc furnaces with the energy saving opportunities being described for each one separately.

Part 1 : Fuel Fired Furnaces

3.1 Fuel Storage and Handling



Coal and furnace oil are the most common fuels in a fuel fired furnace. Fuel storage and handling is an important and often neglected area, but needs to be given attention in order to prevent wastage or contamination of the primary fuels before use. Fuels, which have been contaminated or degraded by poor storage and handling, are difficult to burn requiring more excess air with lower thermal efficiency. The various aspects of fuel storage and handling are more fully discussed in Appendix 4. As a specific case of combustion in coal fired furnaces, coal ash fusibility and clinker formation is discussed in Appendix 5.

3.2 Combustion and its Control

In any combustion process, the chemical combination of oxygen with the combustible part of the fuel releases heat. The requirements of a combustion process are:

- ♦ Fuel
- ♦ Oxygen
- ♦ The three 'T's viz., Time, Temperature and Turbulence

The most common fuels in a furnace are oil, gas and coal. Oxygen is supplied through air. A specific quantity of air is necessary to supply the required amount of oxygen for combustion.

Sufficient time must be available for combustion to be complete. Turbulent mixing of fuel and air is important to ensure complete combustion. The various combustion equipment for solid and liquid fuels are discussed in detail in Appendix 6. The thermal efficiency of a furnace is the ratio of heat input for stock to heat in fuel supplied, expressed as a percentage.

3.3 Heat Distribution



Heat distribution should be uniform. The flame should not touch the stock, since this will increase scale losses. Flames from various burners should not intersect each other, which can be ensured by staggering the burners on either side.

3.4 Furnace Temperature



The furnace must be operated at an optimum temperature. Too high a temperature will cause overheating of stock, leading to excessive oxidation and high thermal stresses on refractories.

3.5 Furnace Loading



There is an optimum load at which a furnace operates at maximum efficiency. Over-loading may lead to improper heating and under-loading means only a part of the supplied heat is taken by the stock leading to low efficiency.

The loading of a furnace contributes significantly in improving the thermal efficiency of a furnace. In an under-loaded furnace, only a small part of the supplied heat is transferred to the stock leading to low thermal efficiencies. In an over-loaded furnace, the stock may not be uniformly heated leading to poor quality of work. In view of these, furnaces should be optimally loaded which can best be determined by trials. However, typical hearth loading rates are shown in Table 3.1.

Table 3.1 : Typical Hearth Loading Rates in kg/m²h

Furnace	Hearth Loading
Heat treatment furnace	147 – 195
Annealing furnace	195 – 293
Drop stamping and forging	293 – 390
Continuous reheating	342 – 489

3.6 Reduction of Excess Air Level



The quantity of air required for burning fuel, based on its combustion and the chemical balance of reactions with oxygen is known as the stoichiometric or theoretical air requirement. Ideally, this quantity of air is sufficient to completely burn the fuel. But in practice, it has been observed that combustion is not complete unless some excess air is supplied to the system. The quantity of this

additional air affects the mass flow rate of the flue gases. By regulating the quantity of excess air, heat loss through the stack can be reduced. The higher the excess air, greater is the volume of flue gas, and hence, higher is the loss through the stack. Besides, flame temperature and rate of heat transfer across the heating surface is reduced.

The quantity of excess air in flue gases can be determined by measuring the percentage of either O_2 or CO_2 in the flue gases. With the measured value of CO_2 , the percentage excess air can be calculated by the following formula:

$$\% \text{ Excess Air} = \frac{\text{Theoretical } CO_2 - \text{Actual } CO_2}{\text{Actual } CO_2} \times 100$$

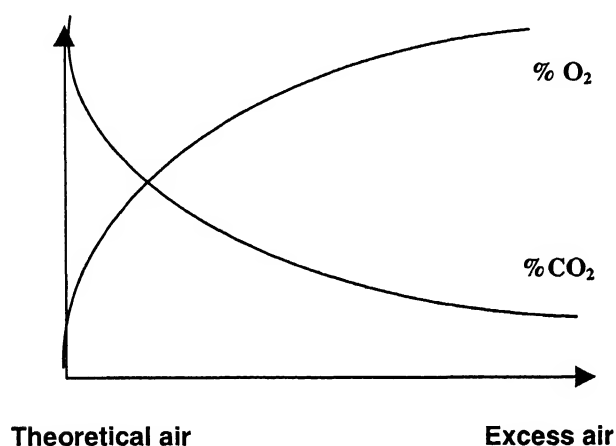


Fig. 3.1 : Oxygen and Carbon Dioxide in Excess Air

As excess air increases, CO_2 reduces and O_2 increases (Fig.3.1). However, CO_2 is not the sole criterion for judging the efficiency of combustion. For example, high CO_2 is attained even when low oxygen/fuel mixture. However, in this case, combustion is incomplete and associated with heavy black smoke. Efforts should be made to achieve optimum CO_2 in a smokeless condition. The appearance of a brown hazy smoke implies good combustion.

Table 3.2 : Oxygen and Carbon Dioxide in Excess Air

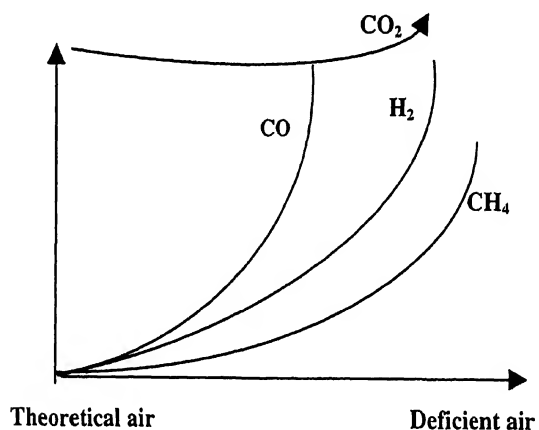
% Oxygen	% Excess air	% CO ₂ in Heavy Oil	% CO ₂ in Coal
1	5	14.7	17.1
2	10	14.0	16.3
3	17	13.3	15.4
4	23	12.5	14.6
5	31	11.8	13.7
6	40	11.1	12.8
7	50	10.3	12.0
8	61	9.6	11.1
9	75	8.8	10.3
10	91	8.1	9.4
11	110	7.4	8.6
12	133	6.6	7.7
13	162	5.9	6.8
14	200	5.2	6.0
15	250	4.4	5.1
16	320	3.7	4.2

The relationship between oxygen, carbon dioxide and excess air in a typical furnace operation is shown in Table 3.2.

3.7 Incomplete Combustion



The formation of black smoke, soot, tar, partial decomposition products and unburnt fuel are all signs of incomplete combustion. The presence of carbon monoxide, hydrogen or methane in waste gases indicates incomplete combustion.

**Fig.3.2 : Variation in Dry Composition of Waste Gas**

Very often, it is due to insufficient air for complete combustion or poor mixing of fuel and air. Fig. 3.2 indicates the approximate variation in dry composition (CO , H_2 and CH_4) of waste gas for a given fuel for a varying amount of deficient air.

3.8 Oxygen Enrichment

Air is mainly composed of 21% oxygen by volume and 78 % inert nitrogen. When combustion takes place, the oxygen combines with the carbon and hydrogen of the fuel to liberate heat. The inert gases of the air absorb heat from the combustion and carry it out of the furnace resulting in loss of heat, also reducing flame temperature and thus reducing the rate of heat transfer to the stock.

If the inert content of air could be reduced, more efficient combustion would be attained. This can be done by addition of oxygen to combustion air. Consequently, when the amount of fuel is not increased, sensible heat loss in the flue gas is decreased due to the smaller heat capacity of the lower volume. In furnaces operated at higher thermal loads, reduction of inert gas results in decrease of waste gas temperature. With the same fuel input, enriched air for combustion raises flame temperature, increasing heat transfer and production rate. The fuel input may be decreased when enriched air is used to maintain the same production rate as obtained with more fuel using ordinary air.

Use of oxygen enriched combustion air offers a method of achieving a measure of stack loss reduction when using oxygen to combust the high calorific value fuels with the technical disadvantages associated with the use of pure straight oxygen. This is shown in Fig. 3.3.

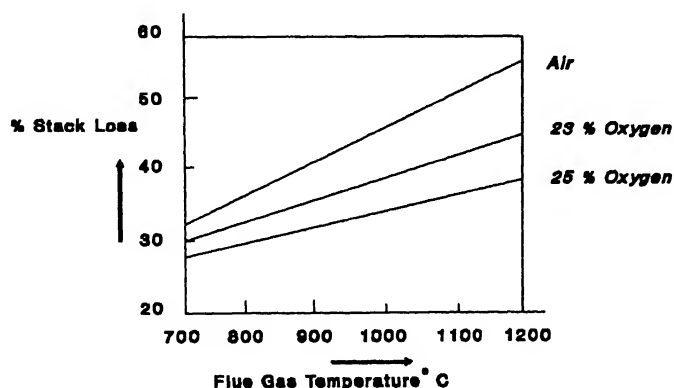


Fig. 3.3 : Stack Loss Reduction with Oxygen Enrichment

3.9 Minimising Heat Loss from Furnace Walls



Heat losses from furnace walls affect fuel economy and depend on:

- ♦ *Furnace temperature*
- ♦ *Ambient air temperature and velocity*
- ♦ *Configuration, emissivity, conductivity and thickness of walls*

Increasing wall thickness or using insulating bricks can reduce heat loss. Outside wall temperatures and heat losses of a composite wall of fire and insulation brick are much lower, due to the lower conductivity of the insulating brick, compared to a refractory brick of the same thickness.

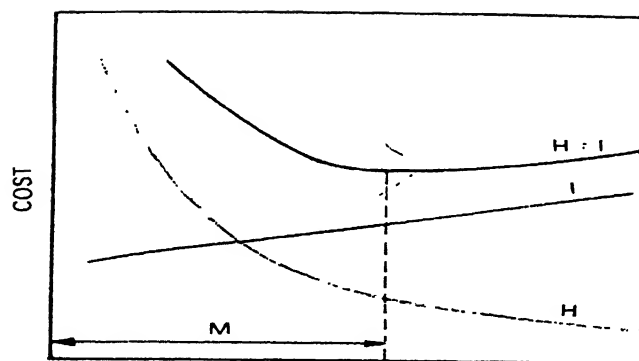
In intermittent furnaces, the operating periods alternate with idle periods. During the off period, heat stored in the refractory during the operating period is gradually dissipated, mainly by radiation and convection from the cold face. The air circulating through the furnace also abstracts some heat. Heat is imparted to the refractories during the "on" period, consuming more fuel in the process.

For a furnace with a firebrick wall of 350 mm thickness, almost 55% of the heat stored in the refractories is dissipated from the cold surface, during the idle period of furnaces operating 8 hours a day. Furnace walls of insulating refractories, cased in a shell, reduce flow of heat to the surroundings. The reduction in heat loss by such insulation depends on the thickness of the firebricks, insulation and continuity of furnace operations.

3.10 Optimum Thickness of Insulation



Insulation of any thermal system implies capital expenditure. Therefore, its benefit in terms of energy and cost saving must be analysed. The effectiveness of insulation lies in the first thin layer, where the most drastic reduction of energy loss takes place. Each subsequent layer proportionately reduces loss of energy. The optimal thickness of insulation is that at which the cost of the heat loss and installation is minimal, when amortised over a period of time (Fig.3.4).



I = Cost of Insulation, H = Cost of heat loss
 $I + H$ = Total cost M = Economic thickness

Fig. 3.4 : Determination of Economic Thickness of Insulation Material

3.11 Combustion Efficiency



Combustion efficiency evaluation indicates the energy transferred from the fuel to furnace. All conventional fossil fuels basically contain carbon and hydrogen which, when burnt, react with oxygen of air forming carbon dioxide, carbon monoxide or water vapour. The efficiency of a furnace depends on the efficiency of the combustion system and utilisation of the generated heat.

After surrendering the heat in the absorption area of the furnace, the combustion products or flue gases leave the system through the chimney, carrying away a significant quantity of heat with them.

Energy balance determines the thermal efficiency of the furnace, comparing the relative values of heat losses. The degree of accuracy with which the total input items correspond with the total output items reflects the accuracy with which the balance is calculated. In a good energy balance, the percentage of unaccounted heat should be less than 6% of the total heat.

The following losses need to be quantified for the heat balance.

➤ Heat loss due to exhaust flue gases

$$\frac{100}{12 \times \%CO_2} \times \left\{ \frac{\%C}{100} \times \frac{\%S}{267} \right\} \times 30.6 \times (T_F - T_A) \frac{1}{4.18}$$

Where :

%CO₂ can be measured using the combustion analyser.

% C & %S from the fuel ultimate analysis

T_F is the flue gas temperature in °C

T_A is the ambient temperature in °C

- Surface heat losses are given by the following formula.

$$= 5.67 \times 10^{-8} \times \left\{ (T_s + 273)^4 - (T_A + 273)^4 \right\} \times 0.86 \times 0.7 \times A_s + \left\{ 2.56 (T_s - T_A)^{1.25} \times 0.86 \times A_s \right\}$$

Where T_s is the average surface temperature °C

T_a is the ambient temperature °C

A_s is the surface area (m²)

- Heat loss due to hydrogen in the fuel

$$= H \times (1.88 (T_f - T_a) + 2442) \times \frac{1}{4.18}$$

Where H is the % hydrogen in the fuel from analysis

T_f is the fuel temperature

Heat loss due to moisture in the fuel

$$\text{➤} = \frac{H_2O}{100} \times (1.88 (T_f - T_a) + 2442) \times \frac{1}{4.18}$$

Where H₂O is the % moisture in the fuel from analysis

- Heat loss due to moisture in air

$$= TA \times SH \times 1.88 (T_f - T_a) \times \frac{1}{4.18}$$

Where TA = Total air supplied

SH = Specific Humidity

- Heat given to the stock (Useful heat component)

- Loss due to flue gas escaping around charging door and openings

For every large opening, heat loss due to openings may be calculated by computing black body radiation at furnace temperature, and multiplying this with emissivity (usually 0.8 for furnace brickwork), and the factor of radiation through openings. Factor of radiation through openings can be determined with the help

of the nomogram as in Fig.3.5. The black body radiation losses can be directly computed from the curve as in Fig. 3.6.

Heat loss = Area of cross section through opening \times factor of radiation through openings \times blackbody radiation

- Unaccounted losses include loss due to thermal storage in refractories and radiation losses from opening of doors during charging and discharging

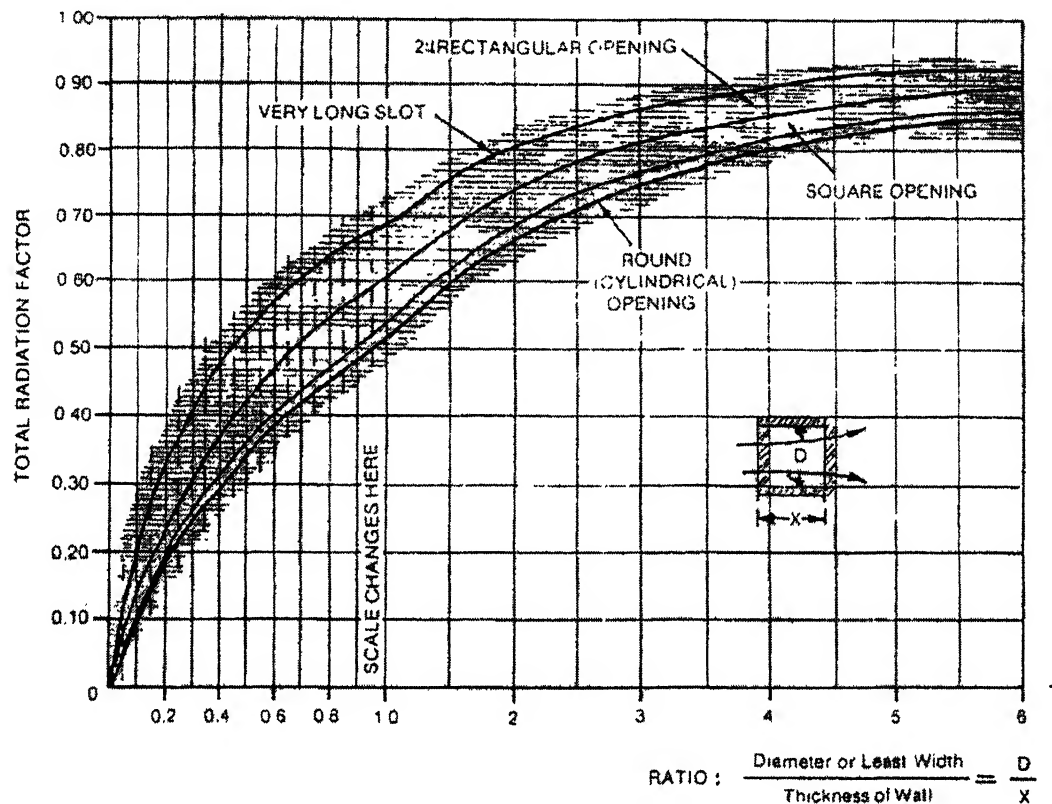


Fig. 3.5 : Radiation through Openings of Various Shapes

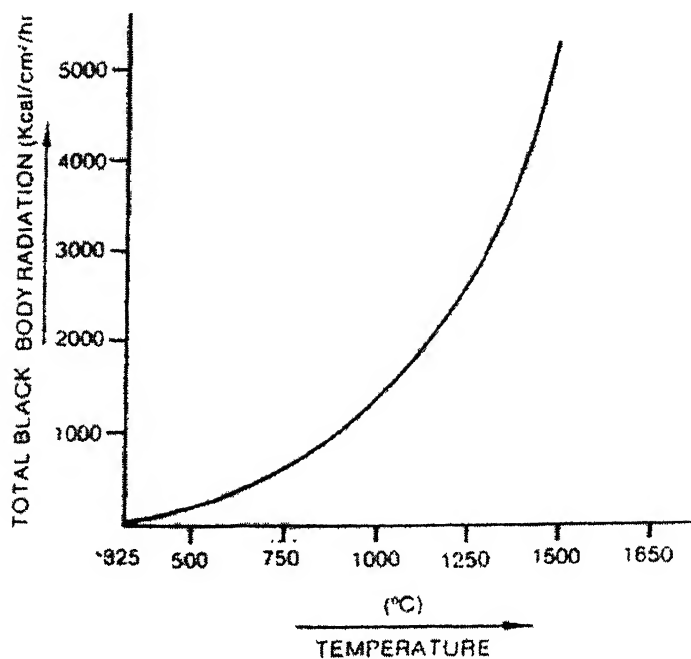


Fig. 3.6 : Black Body Radiation Losses

3.12 Fuel Saving by Ceramic Fibre Lining System



Fuel fired furnaces operate on a semi-continuous basis for 8 to 20 hours a day. To reduce heat loss due to storage, the hot face of furnace can be veneered with ceramic fibre module.

3.13 Waste Heat Recovery



Before examining use of waste heat from a specific process, it is essential to ensure that heat losses have been minimised. Fig. 3.7 highlights opportunities for potential energy savings in a typical furnace. All such opportunities for energy saving should be examined, before considering a waste heat recovery scheme.

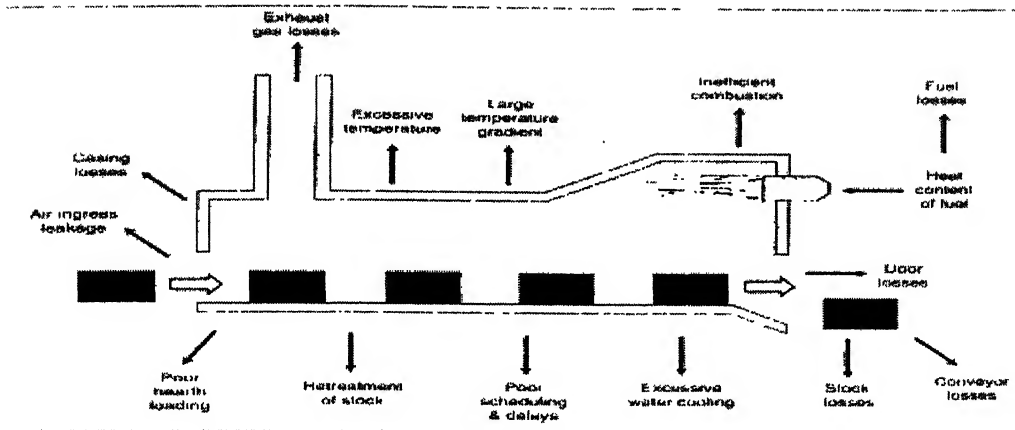
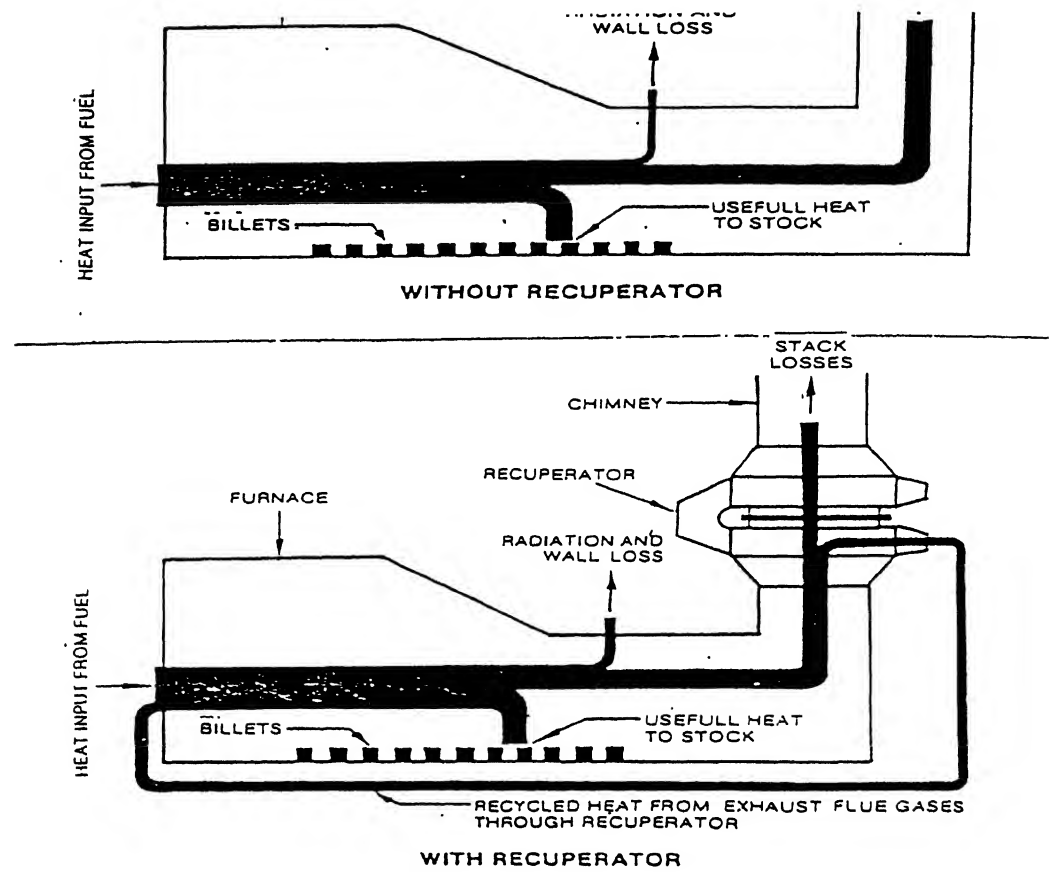


Fig. 3.7 : Opportunities for Reducing Waste Heat

A substantial part of the waste heat can be recovered by installing a recuperator to preheat combustion air required for the burners. For every 16°C rise in combustion air temperature, a fuel saving of 1% can be achieved. The main advantages of using preheated air for combustion are:

- ◆ Heat abstracted from flue gases by combustion air is returned to the furnace, thus reducing furnace oil consumption.
- ◆ Rise in flame temperature results in increased radiation heat transfer. This reduces initial heating time of cold furnace, reducing fuel consumption and increasing furnace availability.
- ◆ Increase in combustion speed further raises flame temperature.
- ◆ Excess air can be reduced, to reduce fuel consumption and scale/burning losses.
- ◆ Overall furnace efficiency is considerably improved.

Fig. 3.8 : Recuperator for Recycled Heat from Exhaust / Flue Gases.



The recuperators for waste heat recovery may be parallel, counter or cross flow type. In a parallel flow recuperator, air and gas flow in the same direction. In a counter flow recuperator, air and gas flow in opposite directions. In a cross flow recuperator, air and hot gas flow at right angles to each other. Figure 3.8 shows a recuperator for recycled heat from exhaust / flue gases.

P3.14 Steam or Hot Water Generation

If waste gases enter a waste heat boiler at 800°C they should be degraded to 250°C at the boiler outlet. Assuming the waste gases are combustion products of fuel oil, with an excess air content of 33% the waste gas heat content would reduce from 45% to 14% of the original heat of combustion. The hot water or steam that can be reasonably generated in such a case would be 80% of the heat extracted from the waste gas. If this steam or hot water had to be generated independently, additional fuel would have been consumed.

3.15 Control of Furnace Draught



It is important to operate a furnace at a slightly positive pressure. Negative pressures lead to air infiltration, affecting air-fuel ratio and furnace temperatures, thus increasing fuel consumption. However, an excessively positive pressure leads to exfiltration, resulting in leaping out of flames, overheating of furnace refractories, reduced brick life and other associated problems. A reasonable pressure to aim for is 0.25 mmwg.

3.16 Structure Heat Transmission and Storage Heat Losses



The heat quantities involved must be supplied by the combustion of fuel in the furnace at the ruling availability. The heat requirement is influenced by the thermal capacity and conductivity of the structure, and the lightest construction consistence with optimum insulation, mechanincal strength, refractoriness and replacement cost will minimise fuel consumption.

For a furnace in continuous operation the structure reaches temperature equilibrium and the heat quantity stored in it becomes small in relation to the heat quantity conducted through it and dissipated from the external surface. Structure thermal conductivity is therefore of greater importance than its thermal capacity.

For a furnace operated intremittently, the structure is unlikely to reach temperature equilibrium and the heat stored in it will be repeatedly replenished and depleted according to the nature of the operating cycle.

Table 3.3 : Effect of Construction on Furnace wall

Furnace Temperature 1300°C

Wall Construction					
Firebrick	345 mm	230 mm	115 mm	-	-
Super hot face					
Insulation	-	-	-	230 mm	115 mm
Backing Insulation	-	115 mm	230 mm	-	230 mm

Continuous Operation

Heat Loss Therms/m ² /	Firebrick Thickness (mm)				
	345	230	115	230 (insulation)	115 (insulation)
Conduction	290.0	122.0	84.0	128.0	68.0
Storage	5.1	5.6	3.6	1.1	1.6
Total over 2000 h	295.1	127.6	87.6	129.1	69.6
% Reduction in		568.0	703.0	56.3	76.4
Total heat loss					

Intermittent Operation 5 – 10 h shifts/wk

Heat Loss Therms/m ²	Firebrick Thickness (mm)				
	345	230	115	230 (insulation)	115 (insulation)
Conduction	2.9	2.4	1.9	2.5	1.4
Storage	10.5	8.6	5.3	2.9	2.5
Total over one week	13.4	11.0	7.2	5.4	3.9
% Reduction in		179.0	463.0	597.0	709.0
Total heat loss					

Although the thermal conductivity of the structure is still important, its thermal capacity must be held to a minimum.

Table 3.3 gives comparative values of conduction and storage heat losses for various types of wall construction when applied to a high temperature furnace operated continuously and intermittently.

In each case 345 mm firebrick is most expensive in terms of total heat losses and fuel consumption. Ceramic fibre with mineral wool backing insulation is an attractive option for furnace chamber walls and roof.

3.17 Furnace Load Factor



When a furnace is held at the operating temperature, it requires a certain amount of fuel to satisfy structural heat transmission losses. If it goes on stream, additional fuel is required to heat the stock. Furnace performance is judged on the fuel consumed per unit stock produced and is best when no load fuel is distributed among the largest number of stocks. Table 3.4 gives a performance analysis for a small furnace operating at various load factors. The specific fuel consumption decreases rapidly as the load factor approaches its optimum value.

Table 3.4 : Effect of Hearth Loading on Furnace Performance

Hearth area = 1.4m² ; Waste gas temperature = 1300°C; Excess air = 10%;
Heat availability = 35%; Final stock temperature = 1250°C

Parameter	Hearth loading (kg/m ² h)			
	98	145	245	365
Steel output (kg/h)	300	450	750	1125
Heat to steel (Therms/h)	1.05	1.58	2.63	3.94
Heat to furnace structure (Therms/h)	2.7	2.7	2.7	2.7
Heat input required (at 35% availability)	10.72	12.21	15.21	18.96
Specific fuel consumption (lts/tonne)	222	168	126	105
Financial saving per tonne steel processed (%)		24.4	43.2	52.8

3.18 Furnace Loading and Utilisation



The initial design of a furnace must consider whether the furnace is to be operated as a batch or continuous type. If stock can be continuously fed at one end of a furnace and discharged at the other, overall efficiency increases. If this is not possible, careful planning of loads is essential. A furnace should be recharged as soon as possible, within metallurgical limitations, to enable any residual furnace time to be used.

One vital factor affecting efficiency is the loading. There is a particular load at which the furnace operates at maximum thermal efficiency. If the furnace is under-loaded, the load consumes a smaller fraction of the heat available in the working chamber and, therefore, efficiency is low. In an over-loaded furnace, the stock may not be uniformly heated, leading to poor quality and again lower efficiency.

Optimal loading is generally obtained by trial, recording weight of the material in each charge, time taken to reach the required temperature and amount of fuel used. Although limitations may be imposed by work availability, attempts should be made to load the furnace optimally. Load disposition on furnace hearth should be such that maximum heat is radiated to the load from hot surfaces of heating chambers and the flames produced. Hot gases should be efficiently circulated around heat receiving surfaces. One more factor affecting optimal loading of furnace is the mismatch of furnace dimension with billet size and production. Typical hearth loading rates are 340-390 kg/m² h.

The stock should not be placed in positions where flame impingement is likely to occur, in the direct path of the burner. It should not block the flue system of the furnace. Cold spots in the stock are likely to develop near openings.

The load should remain in the furnace for the minimum time required to attain the desired metallurgical properties. The higher the working temperature, greater the loss per unit time. Surface defects increase by high residence times, due to oxidation. The rate of oxidation is dependent upon time, temperature and free oxygen content.

3.19 Fuel Efficient Burners



Fuel-efficient burners are now available commercially, which offer a turndown ratio of 7:1 and operate at low excess air levels. They are available in a wide range of sizes, from 20 - 220 l/hr. These burners can handle all types of liquid fuels ranging from kerosene to heavy fuel oils such as Furnace oil and LSHS. They are easy to clean and can be retrofitted immediately, reducing maintenance and shut down time significantly. Accessories such as air blowers and burner blocks need not be replaced. Energy savings of 10-15% have been reported. The cost of burners vary from Rs.20,000/- to Rs.25,000/- depending on the size, with a simple payback period of less than six months.

3.20 Recuperative Burners



Continuous research and development in combustion systems has resulted in a new class of energy-efficient burners known as recuperative burners. The functions of the burner, flue and recuperator are combined in a single compact unit, providing an economical method of waste heat recovery. Fuel and air are supplied to the burner. The flue gases, instead of exhausting out through a conventional flue, are drawn back through the burner and used to preheat combustion air up to 600°C, depending on the type of burner and process temperature. The performance of a typical burner is shown in Table 3.5.

Table 3.5 : Performance of 75 kW Recuperative Burner

Furnace temperature (°C)	Air preheat temperature (°C)	% fuel savings
800	380	17
900	475	23
1000	550	27
1100	625	33
1200	685	38
1300	740	42
1400	780	45

These burners are available in various sizes for temperatures up to 1300°C. Each burner is fitted with an air-driven educator and individual air-gas ratio control system, which automatically compensates for variation in air density at different operating temperatures.

3.21 Regenerative Burners



Industrial oil and gas fired furnaces typically exhaust waste gases containing considerable heat which, when recaptured, can be used to preheat combustion air, thus reducing thermal input required to heat cold air to furnace temperature. Bulk melting and holding furnaces have been converted with regenerative burners to produce a unique level of combustion preheat when fired with a variety of gaseous or liquid fuels, leading to cost effective combustion technology.

With an efficiency of 85-90%, the regenerators produce extremely high levels of air preheat (about 85% of process temperature) which, with a combustion efficiency of up to 75%, bring about fuel savings of almost 65%.

Such burners have been applied successfully to glass melting, forging, annealing, aluminium, remelt and heat treatment of steel strip, tubes, plates and castings in the United Kingdom, Europe, U.S.A, Japan and Australia.

Regenerative burner unit comprises of at least two burners, two regenerators, a flow reversal system and associated controls. The burners and regenerators may be close coupled or joined by a length of refractory lined duct to suit the space available in site.

While one burner fires using air fed to the base of its regenerator, the other burners acts as an exhaust port drawing off waste gas thereby heating its regenerator. When this regenerator is sufficiently charged the reversal valve operates to reverse the system. The regenerator previously cooled is reheated in turn by waste gas leaving the furnace via its associated burner port.

Part 2 : Resistance Furnaces

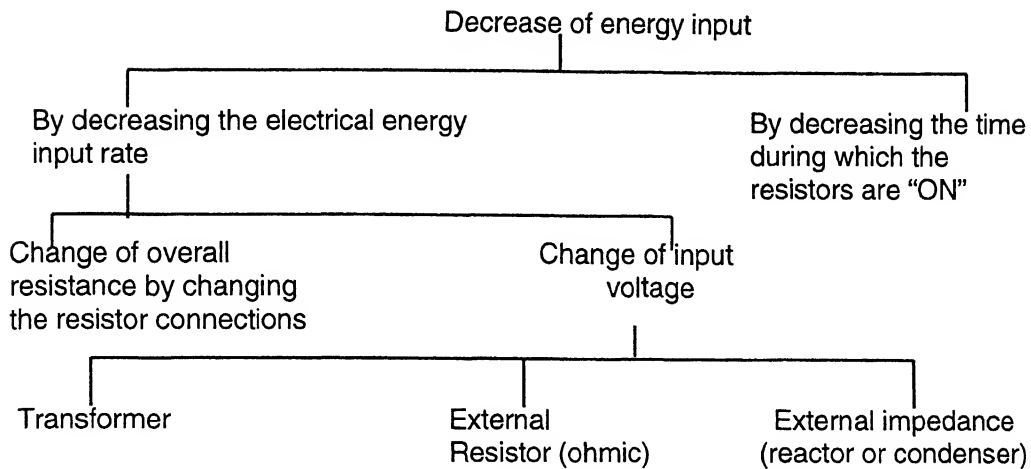
3.22 Temperature Control



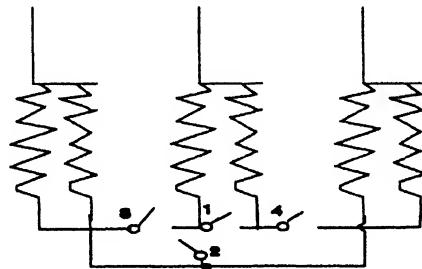
The maximum rate of input energy of a resistance furnace is dependent on the connected electrical load. The energy-input controls can be operated automatically or manually. There could be two kinds of control - one, the lowering of connected electrical load and the other, applying the full connected load at intervals, rather than continuously.

In the first method, the means of control could include reducing the voltage or changing the connections of resistors so as to change the overall resistance of the heaters. In proportional control of resistor heated furnaces, the supply of heat is usually adjusted by variable impedance.

In a batch type furnace, thermocouples should be placed at the centre of the charge but this is not desirable for automatic control. In continuous operation, it is location of temperature control device is immaterial. A continuous furnace can be operated without any control, at least theoretically. If a continuous furnace operates near the danger temperature for heating elements, the thermocouple should be placed, as a burn-out insurance, near the resistors, or as near the charge surface as mechanically practical.

Fig. 3.9 : Control Methods for Reducing Electrical Loads**Reduction of Connected Electrical Load**

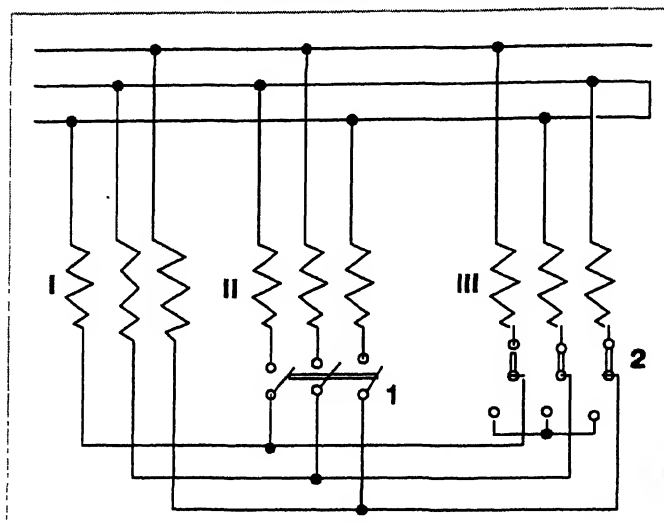
One way to change the input voltage consists of using an auto transformer, transformer with separate windings and taps on primary or secondary side or a transformer with a movable core. The last mentioned are most desirable, because they allow a continuous change of input rate, instead of a change in steps. Their use is, however, limited by their high first cost. Auto -transformers, rather than transformers with separate windings, should be used unless the input voltage is so high that operation of the furnace becomes unsafe. The connected load can be decreased by changing the internal connection of the resistors. The different methods of connecting resistors based on various applications are shown in Fig. 3.10, 3.11, 3.12 and 3.13.

**Fig. 3.10 : Wiring Diagram for Double Y Connection**

Connections	Load %	Switches	In or Out
**Y	100	1,2,3,4	In
* Δ	75	1,2	Out
* Y	50	1,3,4	Out
**Y	25	More switches would be necessary	

** = two circuits in parallel Δ = delta connection
 * = two circuits in series Y = Y connection.

Fig. 3.11 : Decreasing Connected Load



Switch 1/ Switch 2	Connections	Load %	Resistor Groups in Circuit	Watt density of resistors, %
In	Δ	100	100	I,II,III
In	Y	66 $\frac{2}{3}$	100	I,II
Out	Δ	50	75	I,III
Out	Y	33 $\frac{1}{3}$	100	I

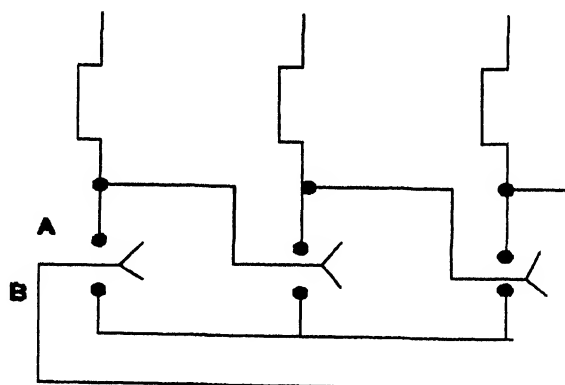


Fig. 3.12 : Delta - Star Connection of Resistors

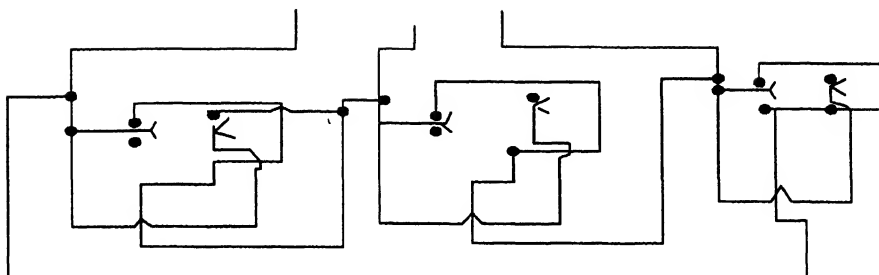


Fig. 3.13 : Series Parallel Connection of Resistors

3.23 Decreasing Effective Time of Heating



The energy consumption of a furnace can be optimised by reducing the time during which the energy is applied. This can be accomplished by switching the furnace on and off manually, but this is an inaccurate practice. Switching can be effected by an automatic device, which connects and disconnects the furnace at regular intervals. Such controllers give successive on and off periods. The total length of the period (on+off) as well as the ratio of time on/off can be adjusted.

3.24 Door Operation



Furnace doors should satisfy the following requirements: tight closure, sufficient overlapping, ease of operation, light weight, avoidance of wear, particularly abrasion, opening as small as possible, durability in order to avoid warping and low heat loss. The size of the door opening is in most instances prescribed by the load. The opening is usually slightly smaller than the inside chamber, thus protecting the resistors.

Door openings are generally large enough to permit a repairman to crawl into the chamber, which is not a good practice. The access to the inside of the furnace should be accomplished by methods other than increasing the door opening. Stops can be used to prevent the door from uncovering the entire opening during normal operation and these stops can be withdrawn when repairs are needed.

The weight of the door is important because of its influence on its opening mechanism and heat storage. Metal frames and lining add to the weight. To keep the weight of the lining low, thin monolithic linings can be used, backed by lightweight insulation.

An efficient means of cutting down heat losses is the use of two doors, one placed in the jam and the other conventionally placed on the outside. The inside door acts as a radiation shield and cuts down draught. The use of such double doors tends to improve the temperature uniformity in the furnace chamber to a great extent.

In continuous furnaces with longitudinal flow, air infiltration through leakage from the door openings must be prevented. If regularly intermittent steps replace the continuous movement of charge, doors can be kept closed, except during the short moments of actual movement.

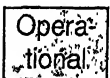
If continuous movement of charge is necessary and the nature of charge permits chain screens through which the charge can pass unhindered, then these screens offer effective resistance to undesired air flow through the openings. A curtain of asbestos strip has been applied successfully for lighter material with sensitive surface.

3.25 Furnace Lids



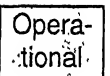
To conserve energy, it is important that furnaces are operated with their lids closed, whenever access to the melt surface is not required i.e., when melting down, holding overnight or during meal breaks. A 45 kW furnace, during handling, will consume about 5 kWh extra, when it is operated without closing the lid.

3.26 Furnace Charging Adaption



A full solid charge may occupy approximately only a third to one half of a pot when molten. Therefore, to obtain a full melt readily at the start of the day, a funnel or prong can be fitted to the furnace top to feed foundry returns or ingots. To avoid overfilling, a weighed charge must be used.

3.27 Loading



The loading of a furnace contributes significantly in improving the thermal efficiency of a furnace. In an under-loaded furnace, only a small part of the supplied heat is transferred to the stock leading to low thermal efficiencies. In an overloaded furnace, the stock may not be uniformly heated leading to poor quality work. In view of these, furnaces should be optimally loaded which can best be obtained by trials.

Part 3 : Induction Furnaces

3.28 Furnace Capacity and Utilisation Factor



The specific energy consumption decreases with increasing furnace size, due to the accompanying decrease in surface area-volume ratio and resulting decrease in specific heat losses. The holding power requirement is governed by the time for which the molten metal is maintained at the required temperature. This depends on the furnace utilisation. Holding requirements are also dependent on furnace size and thus it is doubly important that smaller furnaces are used with high utilisation factors.

Since mains frequency furnaces have to be operated with molten heel and consume up to 20% more energy on cold starting, the operation of under-utilised furnaces has to be studied for the economy of running it continuously or cold starting after set intervals over a week or a fortnight.

3.29 Refractory Lining



The lining thickness of most furnaces is decided based on the experience of the operating personnel. Heat losses through the walls can be as high as 60% of the total losses. But, refractory thickness cannot be increased solely on this basis, as it also affects the power factor and electrical efficiency, due to variations in reluctance between the coil and the charge. Insulation thickness can be increased, for attractive payback periods.

3.30 Electrical Losses and Power Factor Improvement



In induction furnaces, the current carried by the conductors is high. Substantial savings in I^2R losses in cables are feasible by increase in conductor size, conductor material and power factor improvement.

3.31 Charge Raw Materials

The condition of the furnace charge material can result in increased melting time, by restricting the induction effect and limiting the amount of power that can be drawn. Loose scrap or scrap with higher concentration of impurities will restrict the point to point contact. Moisture in scrap, apart from being an operational hazard, also picks up heat for evaporation.

3.32 Furnace Lid and Charging



The furnace lid needs to be opened every time the furnace is charged. Enormous heat losses occur, if the molten metal is exposed. Any delays in charging of low bulk density scrap or failure to close the furnace lid result in lower furnace efficiencies.

3.33 Control of Metal Temperature



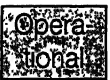
Unnecessarily high tapping temperatures lead to higher energy consumption, longer cycle time and quicker refractory erosion. The tapping temperature is determined by the type of charge and castings. The metal is superheated to compensate for heat losses in transfer of metal from furnace to the ladle, ladle movement and transfer of metal from the ladle to the castings. If the material is to be held in the furnace for long periods due to improper co-ordination between the melting and casting shops or due to non-availability of ladles, the energy losses increase radically.

3.34 De-slagging



The removal of slag is a practice, which meticulously practiced, can result in substantial energy conservation. The continuous removal of slag before each tapping cycle prevents build-up of slag on the furnace walls, which would restrict the output capacity of the furnace and amount of effective power drawn. To counteract this, most furnace operators resort to operation at higher temperatures or occasional high temperature melts to remove the slag from the surface. Both these practices lead to increase in energy losses.

3.35 Molten Heel Practice



Depending on the position of the coils, a molten heel has to be maintained in mains frequency furnaces. The coils normally enclose the lower 60% to 70% of the furnace and to draw full power, the coil portion has to be filled with molten metal. A lower heel maintenance practice means longer melting cycles leading to higher specific power consumption.

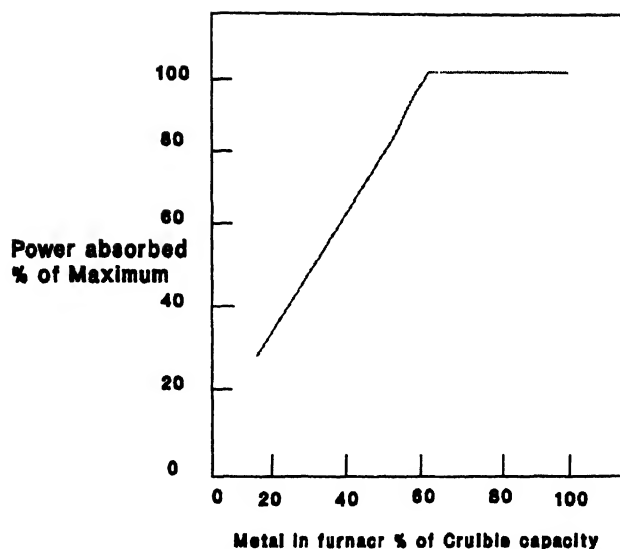


Fig. 3.14 : Power Absorbed vs. Metal in Crucible for Core-less Furnace

Even for medium frequency furnaces operating in the range of 200-250 Hz, a 10 to 20% heel practice can help improve furnace efficiency. Fig. 3.14 shows the relation between power absorbed and metal held in the crucible of a mains-frequency core-less furnace.

Part 4 : Electric Arc Furnace

3.36 Plant Layout



The plant layout should ensure smooth flow of material in ladles from the furnace to the casting bay; Any delay en route or a long, circuitous path would increase heat losses. To ensure higher productivity and efficiency, there should be no bottlenecks in various ladle operations such as furnace tapping, ladle treatment, continuous casting, de-slagging and ladle pre-heating.

3.37 Scrap Quality

Every 1% increase in acid gangue, moisture and iron oxide in scrap implies excess energy consumption of 10-15 kWh. The scrap should be segregated, on the basis of percent impurities, composition and bulk density, before charging. Shredders and presses can increase the bulk density of the scrap with reduced charging operations and melting cycle time. Higher furnace filling can ensure lowest heat losses by minimum exposure of arc radiation to the water-cooled panels.

3.38 Scrap Pre-heating



Scrap pre-heating has emerged as the most effective method of waste heat recovery method. Up to 60% of the heat loss by exhaust gases can be recovered resulting a reduction of specific energy consumption by 30-50 kWh/t.

The other advantages of scrap preheating are reduced electrode and refractory consumption, arc stability, reduced melting cycle time and lesser heat loss. A further development, to substitute electricity with cheaper fuels, is the twin shell furnace with interchangeable roof and burner cover. In this process, while melting takes place in one shell, the scrap is pre-heated to 800-1000°C using fuel-fired burners in the other. The exhaust gases from both shells are used to preheat the scrap in a primary scrap pre-heater. Electrical energy savings of 30% have been claimed, with a corresponding saving in graphite electrode consumption.

3.39 Oxy-Fuel Burners



Auxiliary burners are used in EAFs to eliminate cold-spots. Non-uniform thermal distribution results in increased power consumption and depends on shell shape, furnace capacity and operational conditions. The burners must be mounted so that any sudden collapse conditions of scrap is avoided.

The location, number and type of burners depend upon the size and shape of the furnace. A sole burner, introduced through the slag door, is directed, in turn, towards all the three cold spots in small and medium EAFs. In bigger EAFs, three separate retractable burners are mounted on the sidewalls, but these are highly susceptible to damage from slag splashes. In order to avoid this, the burners are sometimes mounted on the roof-ring with the arc being fired downwards at a tangent, through the cold spot. Oxy-fuel burners are discussed in Appendix 7.

3.40 Oxygen Lancing



Oxygen lancing helps to achieve a uniform temperature distribution by strong stirring of the liquid steel, resulting in reduced melting cycle time. This also serves as a secondary energy input, as a consequence of increased oxidation reactions of carbon. The lance has to be applied at the slag/steel interface to inject oxygen into the bath for decarburisation and into the slag to assist foaming. The quantity of oxygen varies from 15-25 Nm³ per tonne liquid steel.

3.41 Foamy Slag Practice



If carbon, as coke breeze, is introduced by a separate lance along with the oxygen lance, large volumes of carbon monoxide produced stir up a foam through the slag.

This foam covers the electrodes and submerges the arc. Since the arc is not exposed to the water-cooled panels, tremendous reduction in heat losses is possible.

3.42 Submerged Tapping and Liquid Heel



If metallurgical parameters permit the operation of the EAF with a bottom heel of around 15% and slag on top, the Eccentric Bottom Tapping (EBT) furnace offers the following advantages:-

- ◆ No slag carryover into the ladle.
- ◆ Immediate initiation of metallurgical reactions in next heat especially if oxygen lancing is also applied.
- ◆ Arc stability & higher power input during scrap meltdown.
- ◆ Longer service life of bottom refractories, as they are protected from arc during pour down.
- ◆ Possibility of tapping at a lower temperature, because of lower oxidation in steel and less heat losses. A ladle weighing system, which can quickly tilt back the furnace, controls the tapping.

3.43 Ladle Preheating



Ladle preheating is necessary to ensure proper temperature of metal at the caster, longer life of refractories in the ladle and to avoid presence of moisture in the ladle lining at the time of pouring the molten metal. If the ladle is preheated to a proper temperature, extra heating of the metal in EAF can be avoided, saving electrical energy. Energy savings in preheating ladle using oil-fired burners can be achieved by:

- ◆ Ensuring proper combustion and tuning of the burners
- ◆ Close fit between the lid and ladle to bring down flue gas losses
- ◆ Proper co-ordination between preheating the ladles and tapping
- ◆ Recycling preheated ladles and covering ladles after metal has been conveyed to the casting section
- ◆ Use of recuperative burners to tap the heat in flue gases
- ◆ Re-circulating flue gases in ladles before pre-heating

Efficient ladle preheating is given in Appendix 8. The approach to a systematic energy audit is elaborated in Appendix 9.

Section 4 - Case Studies

Certain live case studies pertaining to a wide cross-section of the industry have been discussed here. However, the cost savings and investments have been evaluated for simple payback period at the time of the audit.

4.1 Furnace Loading Optimisation

In an engineering industry, a resistance heating furnace was used for heat treatment of the product. The furnace was loaded to one third of the furnace capacity. The heat treatment cycle and loading of the furnace details are given below :

Furnace capacity	= 180 kW
Loading capacity of the furnace	= 10 T
Stock loaded	= 3 T/cycle
Heat treatment cycle	= Heating to 650°C for 6 hours Soaking at 650°C for 8 hours Cooling in furnace for 4 hours.
Energy consumption	= 860 kWh/cycle
Specific energy consumption	= 286.67 kWh/MT
Annual energy consumption	= 286.67 x 1000 = 286670 kWh/yr
Quantity of stock to be treated	= 1000 T/year

Improving the furnace loading can reduce the specific energy consumption. Energy meter readings were taken after increasing the furnace loading by 9 MT.

Energy consumption	= 1600 kWh/cycle
Specific energy consumption	= 178 kWh/MT
Annual energy consumption	= 178 x 1000 = 178000 kWh/yr
Savings in energy	= 286670 - 178000 = 108000 kWh/yr
Cost savings	= Rs.2.16 lakh/year
Investment required	= Nil
Simple payback period	= Immediate.

4.2 Furnace Openings

In a metallurgical industry, a furnace was used to hold and refine the molten metal before casting. The furnace had an opening to charge the metal, which was kept open throughout. The heat loss details are given below :

Furnace charging door dimensions	= 100 x 50 cm ²
Average consumption of fuel oil	= 52.5 kg/hr
Furnace inside temperature	= 400° C
Ambient temperature	= 30° C
Molten metal temperature	= 750° C
Thickness of brick work	= 30 cm
Width to thickness ratio	= 100/30
Total radiation factor thro' opening	= 0.82
Emissivity of furnace brick work	= 0.8
Black body radiation	= 25 K.Cal/cm ² /hr
Heat loss through opening	= 5000 x 25 x 0.82 x 0.8
	= 82,000 K.Cal/hr
	= 7.80 kg of FO/hr

It was suggested to install a door at this opening and further insulate it with ceramic fibre of density 160 kg/m³ and thickness of 15 cm. The heat loss after providing insulation was :

No of charges per day	= 12
Time required for charging	= 5 min
Heat loss while charging	= $\frac{12 \times 5 \times 82000}{24 \times 60}$
	= 3417 K.Cal/hr
Heat loss while door is closed	= 350 K.Cal/hr
Heat loss after insulation	= 350 + 3417
	= 3767 K.Cal/hr
Energy savings	= 82000 - 3767
	= 78233 K.Cal/hr
Annual saving for 250 days	= 44.7 t of FO/year
	= Rs.2.68 lakh/year
Investment required	= Rs.50,000/-
Simple payback period	= 3 months.

4.3 Controlling Furnace Draught

In a chemical industry, a biogas-fired furnace was used to produce a chemical compound. A performance evaluation test of the furnace revealed:

Furnace capacity	= 50 T/hr
Fuel	= Biogas (methane 64%)
Calorific value of fuel	= 5300 K.Cal/Nm ³
Fuel burning rate	= 266 Nm ³ /hr
Furnace pressure	= - 7 mm wg
Oxygen % in flue gas	= 7.2 %
Excess air levels	= 50%
Sensible and evaporative heat loss	= 20.80%
Radiation and convection heat loss	= 6.38%
Thermal efficiency	= 72.82%
No of burners provided	= 24
No of burners in operation	= 18

Excess air level was controlled by adjusting ID and FD dampers. This also improved the furnace pressure from negative to slightly positive, thereby eliminating air infiltration. The results after adjustment of ID and FD Fan dampers are:

Oxygen in flue gas	= 3.3 %
Excess air level	= 18%
Pressure inside the furnace	= +1.0 mm Wg
Biogas consumption	= 242 Nm ³ /hr
Increase in thermal efficiency	= 2.04%
Savings in fuel	= 266 - 242
	= 24 Nm ³ /hr
Equivalent savings of coal	= 39.62 Kg/hr
	= 285.2 T l/year
Cost savings	= Rs.3.56 lakh/year
Investment required	= Nil
Simple payback period	= Immediate.

4.4 Excess Air Control

In a mini steel rolling mill, a pusher-type oil-fired billet-reheating furnace was used. The excess air percentage in the flue gas was 100%. The furnace details are given below :

Furnace capacity	= 25 MT/hr
Present loading	= 12 MT/hr
Furnace oil consumption	= 500 kg/hr
Furnace operating hours	= 20 hrs/day
	= 6000 hrs/year
Ambient air temperature	= 35°C
Flue gas temperature	= 659°C
Oxygen in flue gas	= 10.6% by volume
CO ₂ in flue gas	= 7.7% by volume
% excess air	= 100 %
Quantity of air supplied	= (500 x 14.1) x 2
	= 14,100 kg/hr
100% excess air sensible heat loss	= 41.6% of fuel input.
20% excess air sensible heat loss	= 25% of fuel input

The furnace inside pressure was negative, causing air infiltration through various openings. It was recommended to close the possible openings and control the draft for 20% excess air level.

% savings in fuel by	
controlling excess air to 20%	= 41.6 - 25
	= 16.6%
Fuel savings	= 500 x 0.166 x 6000
	= 498 T of FO/year
	= Rs. 30 lakh/year
Investment required	= Nil
Simple payback period	= Immediate.

4.5 Waste Heat Recovery : Preheating Combustion Air by Flue Gases

In a mini steel rolling mill, a pusher-type billet preheating furnace was used to heat the billets to 1250°C. Sensible heat losses in the flue gas were 24 percent of the heat input, which was being wasted.

Furnace maximum capacity	= 19 T/hr
Furnace actual loading	= 7 T/hr
Operating temperature of zones	
- Preheating	= 600°C
- Heating	= 1000°C
- Soaking	= 1250°C
Furnace oil consumption	= 273 lts/hr
CO ₂ in flue gas	= 12.75 %
Combustion air supplied	= 4325 kg/hr
Inlet combustion air temp	= 35°C
Ambient air temperature	= 34° C
Flue gas quantity	= 4584 kg/hr
Flue gas temperature	= 630°C
Furnace operating hours	= 5800 hours/year
Heat in flue gas	= 654595 K.Cal/hr
Sensible heat loss	= 24% of heat input

It was suggested to install recuperators to preheat the combustion air to 250°C. This improved the thermal efficiency by reducing sensible heat losses through flue gases.

Recoverable heat from flue gases	= 195274 K.Cal/hr
Energy savings/year	= 18.5 kg of FO/hr
	= 107.3 T of FO
Cost savings	= Rs.6.44 lakh/year
Investment required	= Rs.6 lakh
Simple payback period	= 1 year.

4.6 Surface Losses

In an engineering industry, a resistance-heating furnace was used for sintering the product. The surface heat losses were estimated above the acceptable limit.

Furnace type	= Continuous strip output
Internal surface area of furnace	= 44 m ²
Furnace inside temperature	= 800°C
Skin temperatures :	
Side walls	= 95°C
Top	= 70°C
Bottom	= 55°C
Ambient air temperature	= 30°C
Energy consumption for 8 hrs	= 285 kWh
Energy consumption for one hr	= 35.63 kWh
Furnace operating hours	= 8000/year
Heat loss through surfaces	= 5516.6 K.Cal/hr
	= 6.41 kWh
	= 51280 kWh/year
	= Rs.1.00 lakh/year
Surface loss as % of heat input	= 18%

The acceptable limit of surface losses in heat treatment furnaces is 6-7% of the total input. These surface losses were reduced to a reasonable level by improving the existing insulation. Hot face insulation was provided in the form of ceramic fibre of 50 mm thickness and density of 64 kg/m³.

Heat loss after insulation	= 15384 kWh/year
Savings after insulation	= 51280 - 15384
	= 35896 kWh/year
	= Rs.71,790/year
Cost of 1300 m ² ceramic fibre	= Rs.57,200
Installation charges	= Rs.20,000
Total investment required	= Rs.77,200/-
Simple payback period	= 1.1 years.

4.7 Fuel Efficient Burners

In a steel and alloy industry, an oil fired furnace was fitted with a burner of a low turn down ratio. The furnace was run like this for several years. The thermal efficiency of the furnace was very low compared to furnaces of similar capacity.

It was suggested that the burner be replaced with 8 TPH fuel-efficient burner. Additionally, a blower of 5 HP at 40" W.G pressure was also installed. The new burner had a high turn down ratio of 7:1.

Reputed fuel oil savings	= 10%
Monetary savings in oil	= Rs.1.0 lakh/year
Investment	= Rs.15,000/-
Payback period	= 2 months.

4.8 Ceramic Coating

In a LPG-fired furnace of an automobile industry, the furnace temperature was maintained at 740°C. The cold face temperature was high at 90°C.

The hot face was provided with a ceramic coating. The fuel consumption came down from 61.5 kg/cycle to 56.7 kg/cycle. The cold face temperature could be reduced from 90°C to 75°C.

LPG saved per year	= 14,520 kg
Cost savings	= Rs.1.6 lakh/year
Investment on ceramic coating	= Rs.0.32 lakh
Simple payback period	= 2.4 months.

4.9 Effect of Hearth Loading on Furnace Efficiency

In a slot-type reheating furnace of a steel plant, the hearth loading was inadequate. The hearth area was 1.4 m² and the final stock temperature required was 1250°C. The flue gas outlet temperature was 1300°C with 10% excess air.

It was suggested that the hearth should be optimally loaded. Several trials were conducted at various loads and the fuel consumption, steel output and specific fuel consumption were recorded which is tabulated below :

Parameter	Value			
Hearth Loading (kg/m ² h)	98	146	244	366
Steel output (Kg/hr)	136	204	340	510
<u>Specific fuel consumption:</u>				
Actual litres/hr	30	35	43	53
Litres/tonne of steel	220	172	126	104
Fuel savings (%)		22	45	53

This proposal did not have any investments to be made.

4.10 Improvement in Effectiveness of Recuperator and by Increasing the Air flow rate

The plant is a leading manufacturer of E type glass fibre products such as Chopped Strand Mat, Roving and Woven Roving. The installed capacity of the plant is 6600 TPA.

Waste heat in the exhaust gas is partly recovered by preheating the air by using a metallic recuperator (radiation type). This heated air is used for drying the wet filament in the dryers. The effectiveness of the recuperator is:

Particulars	Value	Unit
Heat input to recuperator		
Fuel and oxygen	919	kg/h
Bubbling air	1.2	kg/h
Loss of ignition	190	kg/h
Total flue gas	1110	kg/h
Exit flue gas temperature	1170	°C
Energy in exit gas	404973	kcal/h
Heat output		
a. Heat given to preheat the dryer air - Recuperator		
Total dryer air	2300	m ³ /h
Temperature of heated air	2760	kg/h
Heat given to the air	278	°C
Heat given to the air	143741	kcal/h
b. Heat given to bottom cooling air from damper fan		
Total air delivered by fan	1827	m ³ /h
	2192	kg/h

Particulars	Value	Unit
Quantity of air taken for cooling at 52 °C (two circuits)	791	m ³ /h
	791	kg/h
Cooling air outlet temperature	52	°C
Heat given to the cooling air	3656	kcal/h
c. Heat rejected to exhaust (by difference)	257576	kcal/h

Effectiveness of recuperator:

Particulars	kcal/h	%
Heat input		
Energy in exit gas	404973	100
Heat output		
a. Heat given to preheat the dryer air - Recuperator	143741	35.49
b. Heat given to bottom cooling air from damper fan	3656	0.90
c. Heat rejected to exhaust (by difference)	257576	63.60

Comparison with design specifications

Particulars	Value	Unit
Design parameters of recuperator		
On maximum side		
Air flow rate – maximum	2000	m ³ /h
	2400	kg/h
Air outlet temperature - maximum	550	°C
Maximum heat recovery	262080	kcal/h
On minimum side		
Air flow rate - minimum	1240	m ³ /h
	1488	kg/h
Air outlet temperature	550	°C
Heat recovery potential	162489.6	kcal/h
Actual recovery as a percentage - on minimum specified parameters	55	%
Actual recovery as a percentage - on maximum specified parameters	88	%

The recuperator is operating at 55% of its design capacity. The poor operation may be due to:

- The recuperator is designed for inlet flue gas temperature of 1450 °C, while the actual temperature is 1170 °C

- ii. The maximum flue gas flow rate is 1560 m³/h

During a trial, the airflow rate to the recuperator was increased by operating the another fan (in addition to the existing fan) with partial suction opening. During the trial, the total air supplied through the recuperator was 3040 m³/h. The air temperature profile was observed over a period. The temperature dropped to 253°C from 278°C and was stabilised at 253°C. A significant improvement in the waste heat recovery was observed after increasing the air flow rate.

Particulars	Value	Unit
Heat given to preheat the dryer air - Recuperator		
Total dryer air	3040	m ³ /h
	3648	kg/h
Temperature of heated air	253	°C
Heat given to the air	170836	kcal/h
Additional heat recovered	27095	kcal/h
	31.5	kW
Achievable savings after considering the additional energy for blower operation	90.0	%
	28.36	kW
Annual electrical energy savings	2.04	lakh kWh
Cost savings	6.12	Rs.lakh
Investment required	Nil	
Payback period	Immediate	
The additional heat recovered will reduce the electrical heater load in the dryers		

4.11 Enrichment of Oxygen in Combustion Air of Fore Hearth

The plant is a leading manufacturer of E type glass fibre products such as Chopped Strand Mat, Roving and Woven Roving. The installed capacity of the plant is 6600 TPA.

The fore hearth of glass melting unit uses LPG as fuel to maintain the temperature of molten of glass in the range of 1230-1300 °C. LPG uses ambient air for combustion and LPG consumption is about 3.85 Mt. per day. Heat loss through flue gas is estimated at 52.9% of total heat input. The huge heat losses are due to very high flue gas temperature (1068-1090 °C) and high quantity of flue gases (2745 kg/h).

The LPG heating in fore hearth is used only to compensate the heat losses. Reducing the losses can reduce the consumption of LPG. Enriching the combustion air with oxygen will reduce the flue gas quantity and thereby reduces the heat loss through flue gas.

The oxygen plant (design capacity of 1291 m³/h i.e., 1850 kg/h) is operating only at 45% and the oxygen is used in the glass melting furnace. Oxygen for the fore hearth can be taken from this oxygen plant. This will also improve the loading on the oxygen plant by increasing the power consumption in the oxygen plant.

Ech: Enrichment.

Particulars	Ambient air	40% Ech*	50% Ech	60% Ech	75% Ech	100% Ech
Oxygen percentage in the enriched air, kg/kg	23.2	40	50	60	75	100
Enriched air required, kg per kg of LPG-Stoichiometric	15.24	8.84	7.07	5.89	4.71	3.54
Enriched air required, kg per kg of LPG after considering 8% excess for complete combustion	16.46	9.55	7.64	6.36	5.09	3.82
Total oxygen in the enriched air, kg per kg of LPG	3.82	3.82	3.82	3.82	3.82	3.82
Nitrogen and others in the enriched air, kg per kg of LPG	12.64	5.73	3.82	2.55	1.27	0.00
Oxygen in the enriched air supplied by ambient air, kg	3.82	1.73	1.15	0.77	0.38	0.00
Oxygen required from the oxygen plant, kg per kg of LPG	0.00	2.09	2.67	3.05	3.43	3.82
Flue gas quantity, kg per kg of LPG	17.46	10.55	8.64	7.36	6.09	4.82
Flue gas temperature, °C	1079	1079	1079	1079	1079	1079
Heat loss through flue gas losses, kcal/kg	4581	2767	2266	1932	1598	1264
Corresponding LPG loss, kg per kg of LPG	0.43	0.26	0.21	0.18	0.15	0.12
Average LPG Consumption, kg/h	161	134.2	128.0	124.0	120.1	116.4
Annual LPG consumption, Mt.per year	1389	1154	1100	1066	1033	1001

Particulars	Ambient air	40% Ech*	50% Ech	60% Ech	75% Ech	100% Ech
Annual LPG savings, Mt. per year	0	234	288	322	355	387
Cost savings, Rs.Lakh/year	0	36.31	44.65	49.95	55.08	60.06
<u>Combustion air blower</u>						
Reduction in energy – consumption in combustion air blower, kW	0	10	15	18	22	30
Energy saving per year, kWh/year	0	86000	129000	154800	189200	258000
Cost savings, Rs.Lakh/year	0	2.58	3.87	4.64	5.68	7.74
Total cost savings, Rs.Lakh/year		38.89	48.52	54.59	60.76	67.80
<u>Oxygen cost</u>						
Oxygen required from the oxygen plant, kg/h	0	280	341	378	413	445
Oxygen required from the oxygen plant, m ³ /h	0	196.2	238.7	264.6	288.8	311.1
Additional electrical energy consumption, kWh/year (@ 0.4kWh/m ³)		674836.1	821089.2	910367.9	993307.5	1070215
Cost of electrical energy, Rs. Lakh (@Rs. 3 per unit)		20.25	24.63	27.31	29.80	32.11
<u>Net Savings</u>						
Cost savings, Rs. Lakh/year	0	18.65	23.89	27.28	30.96	35.69
Investment required, Rs. Lakh	0	10	10	10	10	10
Payback period, months	0	6	5	4	4	3

Considering 50% enrichment:

Net cost savings : Rs. 23.89 lakh

Investment required : Rs. 10.00 lakh

Payback period : 5 months

Equivalent LPG savings : 154.12 MT per year

4.12 Waste Heat Recovery from Fore Hearth by Preheating the Air for Dryers

The plant is a leading manufacturer of E type glass fibre products such as Chopped Strand Mat, Roving and Woven Roving. The installed capacity of the plant is 6600 TPA.

Sensible heat in the exhaust flue gases of fore hearth accounts for about 43% of total heat input. Significant heat in the flue gases can be recovered by installing waste heat recovery unit (Recuperator) in which air can be heated up to 300°C. The hot air can be supplemented to the present heating of the dryers and also can be extended to two dryers.

There are three flue gas outlets. For heat recovery, all the outlets should be joined to a common duct, where a recuperator can be installed. The saving potential has been evaluated for the following conditions:

Option # 1: Installation of recuperator at present situation

Option # 2: Installation of recuperator after implementation of measure "Enrichment of Oxygen up to 50% in combustion air of fore hearth".

Particulars	Option # 1	Option # 2
Flue gas quantity, kg/h	2819	1105
Flue gas temperature, °C	1079	1079
Heat in flue gas, kcal/h	739573	365865
Flue gas exhaust area, m ²		
At Chimney # 1 (in FC # 1) -	0.0361	0.0361
At Chimney # 2 (Between FC # 1 and FC #2)	0.1277	0.1277
At Chimney # 3 (after FC # 2)	0.0266	0.0266
Total	0.1905	0.1905
Estimation of flue gases from chimney (By proportion of area), kg/h		
At Chimney # 1 (in FC # 1)	535	210
At Chimney # 2 (Between FC # 1 and FC #2)	1891	741
At Chimney # 3 (after FC # 2)	394	154
Total	2819	1105
Estimation of flue gases from chimney at 1080 °C and density of 0.275 kg/m ³ , m ³ /h		
At Chimney # 1 (in FC # 1)	1944	762
At Chimney # 2 (Between FC # 1 and FC #2)	6875	2695
At Chimney # 3 (after FC # 2)	1432	562

Particulars	Option # 1	Option # 2
Total	10252	4019
Proposed air temperature, °C	350	350
Proposed flue gas temperature after recovery, °C	400	400
Proposed preheated air quantity, kg/h	5027	1971
Proposed heat recovery, kcal/h	337836	132456
Achievable savings, %	30	50
Energy savings, kcal/h	101351	66228
Energy savings, kW	118	77
Energy savings, kWh/year	824947	539066
Cost savings, Rs. Lakh/year	24.75	16.17
Cost of implementation, Rs. Lakh	15.00	15.00
Payback period, months	8	11

The heat recovery was estimated considering the temperature drop of 200°C, before entering the recuperator. The implementation of this measure and improving the effectiveness of glass melting furnace recuperator may fully substitute the electrical energy used for heating in the dryers. The hot air line from the proposed measure could be connected to the present hot air header. The main line from the header could be drawn to the dryers # 5 & # 6 to use the hot air in these dryers also. To operate the system under safe operating conditions, a dilution air can be given to preheated air whenever the air temperature raises above maximum set point.

4.13 Replacement of Indirect Arc Furnaces by Induction Furnace

The foundry is a leading manufacturer of various SG and MS alloy castings for the automobile sector and the railways.

Unit-I has one direct arc furnace of 500 kg capacity and three indirect arc furnaces (one of 80 kg and two of 30 kg capacity). Out of two 30 kg furnaces only one is in operation and the other is kept as standby. The following table gives brief description of furnaces.

Particulars	30 kg indirect arc	80 kg indirect arc	500 kg direct arc
No. of furnaces	2	1	1
No. of furnaces in operation	1	1	1
Product	Inlet & exhaust tubes	Spacer ring	VSI pigs
No. of heats/month	350 - 500	40 - 50	20 - 30

The furnaces were operating at very low efficiencies, hence resulting in very high specific energy consumption i.e., 1081 kWh/MT and 1811.5 kWh/MT in 30 kg and 80 kg furnaces respectively. This could be brought down to 950 kWh/MT by replacing the existing indirect arc furnace with efficient induction arc furnace in which the furnace efficiency will be in the range of 42 – 47%.

A summary of the feasibility to replace the furnaces is given below.

Particulars	Unit	30 kg IAF	80 kg IAF
Present system efficiency	%	25.48	15.12
Specific energy consumption	KWh/MT	1081	1811.5
Proposed system efficiency	%	45.00	45.00
Specific energy consumption	KWh/MT	950	950
Savings in energy	KWh/year	68316	82236
Cost savings	Rs.lakhs/year	1.776	2.138
Investment required	Rs.lakhs	7.5	10.0
Payback period	Year	3.76	4.16

4.14 Optimisation of Primary and Secondary in a Glass Melting Furnace

The plant has glass furnace of drawing capacity 110 Mt./day with reversible regenerator. Furnace oil is used as fuel and average consumption of oil is 585 liters per hour.

The detailed energy balance was carried out to evaluate the efficiency and the various losses of the furnace which is shown below :

Energy balance of glass melting furnace

Particulars	kcal/h	Percentage
Total energy input	5232000	100
Energy output		
a. Flue gas losses	1268618	24.2
b. Surface heat losses	951900	18.2
c. Loss due to moisture in raw material	152950	2.9
d. Loss due to cooling air	186844	3.6
e. Useful energy and unaccounted losses	2671688	51.1

Optimization of primary and secondary air

The secondary air is used for combustion is preheated by the regenerator. The primary air is used for atomization. The optimum ratio of secondary to total air should be in the range of 0.94:1 to 0.92:1. The primary air should not exceed 8-9% total air requirement.

The furnace is operating at the ratio of 0.88:1 (Secondary to total air) indicates very high quantity of primary air (12% of the total air).

Reducing the volume of primary air (cold air) and replacing with secondary air will result in substantial saving of energy. By adjusting the burner air/fuel nozzles, primary air to the furnace can be reduced. The optimum operating range of primary and secondary air is as follows:

% primary air	Primary air	Secondary air	Savings	FO savings		Cost savings
	M ³ /h	m ³ /h	kcal/h	litre/h	kl/y	Rs. lakh
7.5	594	7328	80232	8.89	71.13	4.62
8	634	7288	71586	7.93	63.46	4.12
8.5	673	7248	62941	6.97	55.80	3.62
9	713	7209	54295	6.02	48.13	3.13
9.5	753	7169	45650	5.06	40.47	2.63
10	792	7130	37004	4.10	32.81	2.13

If the ratio of primary to total air is maintained at 8%, the envisaged annual energy saving is 63.46 kl of furnace oil (Rs.4.12 lakh).

4.15 Replacing Refractory Bricks with Ceramic Fibre Blanket in Heat Treatment Furnaces

The foundry is a leading manufacturer of various SG and MS alloy castings for the automobile sector and the railways.

The plant has three electrically heated furnaces for annealing various automobile parts such as inlet and exhaust tubes. Various process parameters for annealing are tabulated below :

Particulars	Furnace		
	A2	B3	C1
Material	Tubes	Tubes	Tubes
Set Point °C	860	860	860
Soaking duration hours	3.5	3.5	3.5
Cooling Temp °C	600	600	600

Since the furnaces are electrical resistance furnaces, losses are surface losses, heat given to the furnace body and marginal loss due to leaks from door and furnace.

The surface temperatures were exhaustively monitored. Since exact estimation of heat given to the furnace body and heat loss through leaks is difficult, these losses were quantified by subtracting surface heat losses and heat given to the material.

In order to arrive at the total power consumption, the duration of on-time and off-time of heaters during soaking period was recorded.

The furnaces are provided with refractory bricks on the hot face. During the heat balance trials it was revealed that the surface temperatures are high. The surface temperatures and hence the surface losses can be brought down by replacing the refractory bricks by ceramic fibre blanket. Since, the thermal conductivity of the ceramic fibre blanket is lower compared to refractory bricks, the surface temperatures and hence surface losses can be reduced.

The new surface temperatures after replacement with ceramic fibre blanket of thickness 20 mm was arrived by interpolation after equating the surface losses and conduction losses. The table below gives the summary of the same.

Furnace	Before Replacement		After Replacement		* Savings kcal/h
	Avg. surface temp °C	Heat loss kcal/h	Avg. Surface temp °C	Heat loss kcal/h	
A2	78.38	4504.74	59.89	2462.2	1633
B3	96.52	6609.31	59.87	2457.64	3320
Total					4953

% recoverable savings are estimated at 80%

Estimated Savings

Furnace	Savings in power kWh/year	Savings in Rupees / year	Investment required Rs.	Simple payback period
A2	9072	26490	20000	9 months
B3	20265	59173	20000	5 months
Total	29337	85663	40000	

In addition to savings to the tune of Rs.0.85 lakhs per annum, heat given to furnace body can be reduced due to low thermal mass of ceramic fibre.

Energy Savings due to Increase in Furnace Volume

Replacing the existing refractory bricks with ceramic fibre blanket in the furnaces, in addition to bringing down surface losses, will increase the effective furnace volume. This is due to reduction in the insulation thickness from existing 30 mm to proposed 20 mm, which increases the furnace effective loading volume, thereby improves the furnace actual loading, which in turn decreases the number of cycles per month. This measure can result in estimated annual savings of 99,916 kWh (i.e., Rs.2,91,175/-).

4.16 Installation of On-line Tap Changer on 66/11 kV Transformers for EAFs

The plant has two EAFs, each with a rated holding capacity of 20/23 Mt. The furnace transformer rating is 12.10/13.55 MVA with 9 taps with off-load tap changer. The molten metal is tapped in a ladle of capacity 20 T through the tapping spout. The furnace has water-cooled side walls and furnace roof. The roof has only three holes for electrodes and the exhaust fumes escape from the electrode openings and slag door. The fumes are extracted through a fume hood.

The scrap quality is good with a high bulk density and minimal dust, rust and other impurities. The furnace is charged only once during a heat by a charging bucket. Initially, coke and limestone are charged and then scrap is added on top. The roof is then shut and the arc initiated. The electrodes are cooled externally by spraying water on them. Hot heel practice is not followed in the plant.

The specific energy consumption fluctuates between 560 and 730 kWh per Mt. of tapped metal. The electrode consumption is nearly 6.25 kg/Mt. The oxygen consumption is about 250-300 Nm³ / heat.

The arcing period is between 120-140 minutes. This is because, after arcing for 70 minutes at high tap, a molten bath is formed but there is still substantial scrap at the periphery of the furnace. The scrap has to be melted but arcing has to be done at lower tap as the arc becomes naked and higher tap setting would mean excessive loss and heating of roof and wall refractories. The scrap sticking to the sides also poses the problem of suddenly falling into the bath and creating unstable conditions in the furnace.

Another reason for prolonged arcing time is the low voltage received at the furnace. This results in very low rate of energy being released by arcing even at high taps resulting in higher energy consumption. The longer duration of furnace arcing results in more losses as heat is being continuously lost via the cooling water, exhaust fumes and radiation and convection from the furnace shell.

The shell temperatures revealed no excessive losses. Outer surface temperatures were below 60°C on the surface above the slag line and 140°C below the slag line. Refractory consumption is higher due to longer heating and naked arcing.

Specific electrode consumption is also higher particularly because the hot exhaust fumes vent from the three electrode holes and not from a separate fourth hole. This is despite the external electrode cooling arrangement.

An energy balance for the furnace revealed that, on an assumption of 20 tonne of metal tapping at 1710°C in each heat with a power consumption of 13000 kWh, the heat given to metal is nearly 61.6% of the electrical power input. An additional 6.6% heat is given to the slag. Cooling water from the water-cooled cables and armatures carry away nearly 8.5% of the power input. The radiation and convection loss from the furnace shell is only 3.4%. The water-cooled panels contribute 3.1% of equivalent power loss. The remaining 16.7% of power input is lost through hot exhaust fumes, thermal inertia of the furnace and roof, directly radiated out by the arc.

The incoming voltage to the EAF varied between 7.8 to 9 kV, when the grid voltage was low. This resulted in longer heat time in the furnace and higher specific energy consumption. The total energy consumption per heat increased

by 1500-2000 kWh for the same quantity of metal tapped. The voltage received on the 66 kV cannot be corrected on the 11 kV secondary of 15 MVA transformers, since they transformers only off-load tap changers.

On-load tap changer should be installed on 66/11 kV, 15 MVA transformers. This will help improve voltage loads received on the primary of the furnace transformers and reduce energy consumption by 2000 kWh per furnace per day. This amounts to an annual energy saving of 12-lakh kWh equivalent to Rs.48 lakhs

4.17 Operating (Charging, Melting and Pouring) Practices of Induction Furnaces

Each furnace was studied for its operating parameters for more than three heats and out of which the best comparable heat cycle was selected for the detailed analysis.

During the heat cycle study, simultaneous measurement and monitoring of electrical energy parameters were carried along with meticulous observation of melting practices.

The summary of the analysis is as follows:

Induction Furnace MF # 1 (Melt: SG Iron)

- ♦ The error in energy meter recording was estimated at 5.7%.
- ♦ The heat cycle (pouring to pouring) is about 59 minutes
- ♦ During the initial charging and melting, for about 15 minutes furnace was operated only at 40-60% of rated power. Thereafter power to furnace was above 700 kW. This aspect indicates low power input to furnace during first ¼ of heat cycle.
- ♦ The raw materials are charged based on standard past experience
- ♦ About 80% metal is charged, before taking the sample for the analysis. The remaining 20% of crucible volume is loaded after obtaining the sample analysis.
- ♦ Time taken for sample analysis is about 8-10 minutes and normally the furnace was switched off during this period.

- ♦ The first batch sample analysis indicates the short fall/excess of different elements, based on this the additional material is added to achieve the required composition and quantity.

Induction Furnace MF # 2 (Melt: WCB)

- ♦ The error in energy meter recording was estimated at 2.8%.
- ♦ The heat cycle (pouring to pouring) is about 1hr 48 minutes.
- ♦ The cycle time is higher than MF # 3 and one of the reasons is low power capacity of the furnace
- ♦ The power to the furnace was varied very frequently due to empty space in the crucible (cap V), excess charge, sample analysis delay, poking operation & degassing operation.
- ♦ The recorded electrical parameters indicate that about 35-40% of the heat time the furnace was operated at 70-80% of rated power. The raw materials are charged based on standard past experience
- ♦ About 80% metal is charged, before taking the sample for the analysis. The remaining 20% of crucible volume is loaded after obtaining the sample analysis.
- ♦ Time taken for sample analysis is about 8-12 minutes and normally the furnace was switched off during this period.
- ♦ The first batch sample analysis indicates the short fall/excess of different elements, based on this the additional material is added to achieve the required composition and quantity.

The specific energy consumption in the furnaces is slightly higher than optimum value may due to the one/all factors specified above. Potential to reduce the energy consumption exists by practicing the following measures.

- ♦ Meticulous weighing and charging of input material based on proposed output. Though this is a trial & error method the results can be obtained to reduce the time taken for melting the additional charge after the sample analysis. Since in present practice about 20% of the material is added during post sample analysis for makeup/compensate the composition of liquid metal. This compensating material can be reduced to 10% after successful trials.

- ◆ Possibilities should be explored to supply the full power during the melting
- ◆ Reduction in time taken for sample analysis & communication of results can significantly reduce the heat time and thereby lower the specific energy consumption. Use of intercoms/alarms, pneumatic conveying and advanced logistical preparations may help to reduce the time for sample analysis.
- ◆ In addition to above, use of recently introduced energy optimiser for melting operation shall create a benchmark and enforce conscious practice to complete the job within the set goal. This energy optimiser senses the inverter output power and integrates into energy delivered to the furnace. A thumb wheel is provided to set predetermined energy requirement for melting the material to the desired temperature.

Setting of energy parameter should be based on lowest achieved energy consumption figure during the past fortnight. Close monitoring of set goal and analysis of the reasons for not being able to comply with the benchmarking if any, shall ensure reaching the optimum level of energy consumption.

The energy saving potential by implementing the above measures is given the following table.

Furnace		MF # 1	MF # 2	Total
Losses component (Refer energy balance)	kW	331.48	228.7	560.1
Possible reduction in time	min	5	7	12.0
Reduction in energy	kW	27.6	26.7	54.3
Operating days	per year	330	330	-
Operating hours per day	No.	24	16	-
Energy saving potential	kWh/year	218774	140856	359630
Realizable saving potential	%	80	80	-
Estimated energy savings	lakh kWh/year	1.75	1.13	2.88
Annual cost savings	Rs. lakh	6.30	4.06	10.36
Investment required	Rs. lakh	1	1	2.00
Payback period	Months	2	3	2

4.18 Reducing Thermal Inertia of Batch Furnace by Hearth Replacement

A smelting plant has four annealing furnaces for heat treating SG-iron, malleable iron and steel. These are all electric resistance furnaces with heaters. The furnaces are provided with thermocouples to measure the temperatures of the zones. The cycle time for SG-iron is 25 hours, of which the heating cycle is 9 to

10 hours and soaking cycle is 2 hours at 930°C. For malleable iron, the heating cycle is 12 to 14 hours and soaking time is around 18 hours at 960°C. The normalising cycle for steel is around 12 to 13 hours at 930°C. The furnace is a rectangular bell furnace insulated inside with ceramic fibre, provided with PID controllers in a separate control room, which includes working temperature and safety controllers. The materials are placed on a hearth-like arrangement and the furnace covers the material in such a way that there is no air gap at the bottom. The air gap is avoided by providing sand on all sides and corners. Depending on the type of application (annealing or normalising) and customer requirements, the zone temperatures are set to adjust the material temperature. Based on these temperatures, the heaters are on and off during the soaking period to maintain a constant set temperature.

The average electrical energy consumption for heat treating SG-iron is 297 units/tonne, 421 units/tonne for malleable iron and 363 units/tonne for steel. The hearth of the furnace is made of four layers of insulation bricks. The top portion has 6 hearth plates of 53 mm thickness. The second layer has firebricks, followed by vertical bricks and bottom layer bricks. The total thickness is about 553 mm.

The no-load was conducted for six hours, when the furnace took 4 ½ hours to reach stabilisation set temperature. After stabilisation also, the furnace consumed nearly 80 to 100 kWh, accounted as conduction loss, surface loss and other leakage.

By replacing the hearth with three layers of materials such as hearth plate, followed by two layers of fire bricks and a layer of calcium silicate block, some of the fixed losses due to thermal inertia and conduction losses could be reduced. Even if the hearth is loaded to 12 tonnes, these materials can withstand this load. Since the thermal conductivity is low, the heat losses can be avoided.

Energy Savings by Replacing Hearth Material

Furnace No.	Units	HC #1	HC #2	HC#3	HC#4
A. Existing Hearth Arrangement					
Hearth plate thickness(top layer)	mm	35	53	35	53
Hot face fire brick thickness	mm	110	70	110	70
Vertical bricks thickness	mm	250	380	250	380
Bottom layer brick thickness	mm	50	50	50	50
Total hearth thickness	mm	445	553	445	553
B. The proposed Hearth Arrangement					
Hearth plate thickness(top layer)	mm	25	25	25	25
Hot face fire brick thickness	mm	140	140	140	140
Calcium silicate bricks	mm	300	300	300	300

Potential Energy Savings

Furnace Details	Units	HC #1	HC #2	HC#3	HC#4
Hearth plate thickness	mm	25	25	25	25
Volume of hearth plate	m ³	0.062	0.062	0.062	0.062
Total weight of hearth plate	kg	276	276	276	276
Hot face fire brick thickness	mm	70	70	70	70
Volume of hot face brick	m ³	0.458	0.458	0.458	0.458
Total weight of hot face brick	kg	453	453	452.54	452.54
Calcium silicate block thickness	mm	300	300	300	300
Existing heat loss by thermal inertia	kcal	389259	418645	405588	418645
Heat energy saved	kcal	242628	277367	264311	272013
	kWh	282	323	307	317
Energy savings per hour(expected)	kWh	47	54	51	53
Annual furnaces charging	No.	180	184	203	181
Average heating hours per charge	Hrs	12	12	12	12
Energy savings per year	kWh	117191	118687	139630	114499
Energy savings by avoiding conduction loss per charge	kWh/charge	81	94	80	94
Energy savings by avoiding conduction loss per year	kWh	14589	17239	16225	17239
Total energy savings	KWh	131780	135926	155855	131738
Total cost savings (@ 3.6 /unit)	Rs.lakh	4.74	4.9	5.61	4.74
Investment required	Rs.lakh	2.0	2.0	2.0	2.0
Payback period	Years	0.42	0.41	0.36	0.42

Section 5 - Checklist

5.1 Coal Fired Furnaces

Storage and Preparation

- ◆ Stack coal in neat heaps not exceeding 1.5 meters in height and limit the individual heaps to 200 metric tonnes.
- ◆ Stack coal on hard ground and ensure a tightly packed heap to subdue ventilation, which could lead to spontaneous combustion.
- ◆ Coal should be properly sized as per the requirement.
- ◆ The wetting of coal should be done carefully and the quantity adjusted according to the content of fines in the coal.
- ◆ Do not store coal in big heaps and on slushy surfaces.
- ◆ The wetting of coal is limited when the fines content reaches a limit of 40%, further addition of water should be avoided in case it is more than 40%.

Coal Combustion

- ◆ Maintain coal size and wetting of coal to recommended limits as far as possible to avoid segregation and choking of the fire grate.
- ◆ The primary as well as secondary air may be regulated according to the coal bed thickness and volatiles contents of the coal being used.
- ◆ Periodic sampling of exit flue gases and corresponding adjustment of air supply are important in order to maintain optimum level of carbon-di-oxide percentage (12-14%).
- ◆ Keep the blower position off when ash is cleaned from fire grate.
- ◆ Stoke the fuel (in hand firing system) in small quantities and at more frequent intervals.
- ◆ Set the chimney damper in such a position that the combustion chamber works under slightly positive pressure.
- ◆ Clean the clinker formation on bridge and side walls as and when it occurs.
- ◆ Complete cleaning of fire grate and ash pit may be done during weekly off.
- ◆ In the case of a fixed grate natural draft system a castable grate is recommended instead of a 'lose' bars grate.
- ◆ Close the damper when the furnace is stopped.
- ◆ Do not permit segregation of coal particles on the fire grate.

- ◆ Do not operate with too thick a fuel bed.
- ◆ The supply of primary and secondary air should not be same at different fuel bed thickness.
- ◆ Do not operate the blower during ash cleaning.
- ◆ Do not fire coal in case there is a big clinker formation.
- ◆ Do not operate the furnace in a negative draft particularly in the case of a re-heating furnace.
- ◆ Do not disturb the fuel bed too much and too often by “hooking” and “poking”.
- ◆ Avoid maximum opening of surface doors.

Waste Heat Recovery

- ◆ Preheat both the primary as well as secondary air for combustion.
- ◆ In case the exit flue gas temperature is more than 1000°C use a ceramic recuperator or regenerator for waste heat recovery system.
- ◆ Never allow more than 950°C flue gas temperature to reach a metallic recuperator. Use a dilution air blower if it is excessive.
- ◆ Bypass flue gases during cold start up till it achieves the desirable temperature.
- ◆ Check all joints to prevent air leaks.
- ◆ The insulation on a hot air pipe line should be thoroughly checked.
- ◆ Soot and flyash deposition both inside and outside the tubes should be cleaned regularly.
- ◆ Do not allow combustion air temperature to increase more than 150°C, in case of fixed grate firing system.
- ◆ Do not locate metallic recuperator (shell and tube type) near the furnace (important for high temperature furnaces).
- ◆ Do not locate dampers just before and after a recuperator.
- ◆ In the case of a regenerator do not set reversal time either too short or too long.
- ◆ Do not use cheap refractory in regenerator chequer brick (particularly in the upper layer).

Reducing Heat Losses

- ◆ Appropriate thermal insulation of furnace surfaces is required, if skin temperature is more than 60 – 70°C.
- ◆ Set the chimney damper in such a position, as to maintain furnace pressure slightly positive, to obviate ingress of cold air.
- ◆ Furnace doors and other openings should be kept closed as far as possible to prevent excessive radiation losses.
- ◆ The material should be kept inside the furnace and not allowed to project outside the furnace.
- ◆ Do not use thermal insulating material like glass wool or mineral wool if there are small leakage in the furnace structure.
- ◆ Do not use cold face insulating bricks without proper support.

5.2 Oil Fired Furnaces

- ◆ Ensure proper storage, handling, preparation of fuel for efficient combustion and good flame temperature.
- ◆ Ensure uniform heat release and constant atmosphere throughout the furnace width by controlling the air and flue gas distribution to the furnace chamber.
- ◆ Flame path should be controlled to prevent burning of the stock or impact on the furnace refractories leading to rapid failure.
- ◆ Maintain optimal excess air levels, so as to ensure complete combustion while keeping stack gas temperature at its minimum. This is essential to ensure efficient furnace operation.
- ◆ Ensure static pressure control related to the furnace geometry to restrain air infiltration or blowout of the flue gas. A reasonable pressure to aim for is about 2.5 Pa (0.01 in W.G.) and this should be measured at the hearth level to avoid the buoyancy effect.
- ◆ Location of the load in a furnace should be carefully done, as a badly located load can spoil the operation of a good furnace by affecting the recirculation of gases.
- ◆ Furnace should always be loaded to the maximum extent possible as the furnace performance is judged on the fuel consumed per unit of stock produced.

- ◆ Workout the economic thickness of insulating bricks based on computation of furnace surface heat losses. Ceramic fibre insulation with mineral backing is an attractive and relatively new form of construction for furnace chamber walls and roof.
- ◆ Investigate waste heat recovery option from exhaust gases to preheat combustion air.
- ◆ The location of waste gas off-take should in general be as far from the burners as possible, but their location is not critical with furnaces operating under slight positive pressure.
- ◆ When air (or fuel) is supplied to several burners by a manifold, it is important that this be large enough to act as plenum chamber, otherwise the flow to some burners will be excessive and the others may be starved, resulting in a badly heated furnace.

5.3 Electrical Resistance Furnaces

- ◆ Oven construction and design of heat circulating system should depend largely on the kind of products that will receive the heat. i.e. shape, mass density, stacking arrangements and materials.
- ◆ Use of thermocouples for each zone working with controlling instruments is vital for any electrically operated resistance furnace. If possible excess temperature monitoring thermocouple should be employed to disconnect the power supply in the event of mal-operation of the normal temperature control devices.
- ◆ Furnaces with fan assisted convection heat transfer, the energy consumed by recirculation fan motors should be optimised. When such fans are more in number or whenever furnace loading is subject to variations, it is justifiable to use variable frequency drive for energy savings.
- ◆ The furnace opening should be kept to minimum as far as possible. In many cases the feeding door of the continuous heating furnace has more opening than the height of the product that is fed in.
- ◆ The furnace should be loaded optimally by planning the material flow to and from the heat treatment departments. This assumes importance as the performance is basically judged on the energy consumed per unit of stock produced.

- ◆ The furnace should be effectively insulated with ceramic fibre backed mineral wool. In continuous long-term cycle furnaces the insulation is to prevent the escape of heat through the walls and roof. In intermittent or short-term cycle furnaces, it is to reduce the heat storage loss while not neglecting to reduce the external surface loss. Ceramic fibre is the ideal insulating material for intermittent batch furnaces.
- ◆ The mass of the supporting structures of any product should be as low as possible for the given mechanical strength.

5.4 Induction Furnaces

- ◆ Keep holding periods to minimum as the cooling water losses are very high with longer holding periods.
- ◆ Minimise the tap-to-tap time to reduce the radiation and convection losses and for effective capacity utilisation.
- ◆ Use pyrometers to measure the accurate temperature of melting to avoid the unnecessary superheating of the liquid metal.
- ◆ Minimise the opening of furnace lids, slagging door, etc.
- ◆ Explore the possibility of charge compacting and preheating.
- ◆ Monitor the cooling water inlet and outlet temperatures and flow rates to assess the condition of the furnace refractory lining and the coil losses.
- ◆ Determine the melting capacity of the furnace as precisely as possible for the given type of casting or for mild steel ingots. This is because too large a capacity than needed would mean very high heat losses.
- ◆ Match the furnace capacities and production rates judiciously for maximising the furnace load factor. (to reduce the cost of energy per unit of output).
- ◆ Maintain the performance index (kg/h at a specified temperature per kVA) on a regular basis for effective performance monitoring of the furnace.

5.5 Electric Arc Furnaces

Elimination of delays is one of the surest methods of saving energy. It is essential that the entire operation of the furnace, furnace preparation and repair, charging, melting, refining, finishing and tapping are all well planned.

Charging

- ◆ The initial charge should always be of maximum density to achieve the required heat tonnage with a minimum number of recharges after the initial meltdown starts.
- ◆ The selection of charge should be carefully done to suit the meltdown operations. In case of alloy steel production it should be to result in a meltdown bath analysis that is close to the product specifications. Carbon in the charge may be adjusted to yield suitable melt required for common steels, or carbon percentage may be adjusted considerably more for higher quality, in order to gain full benefits of the carbon boil.
- ◆ The non-conductive material should be excluded from the charge as completely as possible to avoid the unnecessary heating up.
- ◆ The addition of lime to be charged should be determined after the analysis of scrap quality and the desired product.
- ◆ The charge placement in the furnace should be planned to attain efficiency in charging and meltdown with particular emphasis upon the maximum degree of heat absorption.
- ◆ To start with, a small quantity of light stamping scrap is to be positioned to cushion the impact of the heavier pieces of scrap as they fall into the furnace. Heavy scrap should be placed in the centre of the charge and should be located within the electrode. The furnace charge should be completed by placing sufficient quantity of medium and low density scrap on top of the heavier pieces.

Melt Down

- ◆ The electrodes should be lowered as closely as possible to the charge by push button operation to reduce the time required for the automatic control to lower the electrodes and strike the initial arc.
- ◆ Suitable voltage levels should be selected to inject enough energy into the arc to allow the electrodes to bore down into the charge until they approach the

heavy scrap at the furnace bottom. This practice permits the greatest absorption of the arc energy by the charge and promotes the economic use of electric power.

- ◆ Once the primary bath has been formed at the bottom of the furnace, the scrap is melted by heat transmitting through the steel bath as well. Melting continues at this power level until the bath temperature requires this power. In some cases, it may be necessary to cut off power during this late melting period to raise the electrodes and to push any scrap which may have clung to the side walls above the bath.
- ◆ If the scrap is not dense enough to get the required charge weight into the furnace in the initial charge the remaining of the scrap is charged as soon as the scrap is melted to the level mass.

Typical Delays that Affect Energy Input

- ◆ The melting procedure is seriously affected by delays in crane service or in scrap delivery, shutdowns for power demand and mechanical failures.
- ◆ Scrap charge of incorrect chemical analysis sometimes necessitates changing the furnace schedules and melting to different specifications. The analysis of above delays (due to incorrect chemical analysis of scrap) and energy losses due to rescheduling of furnace loading should be reviewed for optimising energy consumption (thus re-storing normal furnace schedules).
- ◆ Pieces of scrap placed along the sidewalls of the furnace may fall against and break the electrodes during meltdown.
- ◆ Electrodes may be broken by contact with any large concentration of insulating material in the charge, such as lime stone, since the electrode drive will continue to exert downward force as long as current in that leg of the circuit is low.
- ◆ Errors in the selection of power input levels may result in slow melting rates and damage to the furnace roof lining.

Section 6 : Economic Analysis of Investments for Energy Conservation

When any conservation opportunities are to be implemented, most measures do not require investments. However, it is possible that an investment, marginal or substantial, is sometimes incurred for specific energy saving opportunities. And, transferring the implementation from paper to actual practice involves making a decision - to invest or not to invest.

Usually, decisions are made regarding alternative solutions for utilisation of capital. At the outset, the decisions must not conflict with the objectives of the enterprise. These objectives can be constrained by social considerations or governmental regulations. They can be influenced partially by the owner's tastes or time required for implementation. However, the prime objective does not deviate from profit maximisation.

In order to aid the decision-makers, there are certain economic methodologies, which are followed. These are briefly discussed, although progressing beyond basic concepts would be beyond the scope of this manual.

All these methods are more or less reliable, depending on the accuracy of evaluation of the cash inflow and outflow, estimation of the discount rate (cost of capital) and prediction of the possible rate of increase of the energy price. Within these limitations, the most precise method is the Present Value Criterion, which compares the present value of all future after-tax cash inflow and outflow over a specified period of time to the present value of the cost of investment for the investment.

Although it may appear elementary, one has to recall here the fundamental rule of sunk costs, which says that in taking decisions about future investments, no role is played by past costs.

For example, when a new line of products is considered in a factory, the original book value of the existing old machinery already installed as irrelevant from the point of view of future cost evaluation. What is relevant is the present book value of the equipment, in the case that the old machinery can be sold or partially used to substitute the purchase of the new machinery. If the old machinery cannot be sold or used in the new production it is a "sunk cost" and has no relevance to the investment decision concerning the new machinery.

6.1 Present Value Criterion

The net present value (NPV) is defined as the difference between present worth of savings and cost of investment. The investment should be made if NPV is positive, and should be discarded if NPV is negative.

The present value method converts the money time series corresponding to the savings to an equivalent single amount at the date (year 0) when the decision to invest is to be taken. The present value criterion then compares this equivalent amount to the capital to be invested.

$$NPV = p \times \frac{1}{(1 + r)^n}$$

Where p = future payments and income

r = pre-determined discount rate

n = number of years for which NPV is calculated

NPV indicates the return that the management can expect from the project at various discount rates. It can also be used to compare various projects with similar discount rates and risks, as well as compare them against a benchmark rate.

Internal Rate of Return (IRR) is the threshold rate at which the NPV is zero. It is the rate of return received for the project considering payments and income at regular intervals. This is commonly used for analysing investments in projects. A project is considered viable, if its IRR is greater than the interest rate offered by financial institutions for investing the capital with them that would be otherwise invested in the project.

6.2 Average Rate of Return Criterion

The average rate of return on investment criterion is not so precise as the present value criterion but it can provide a preliminary guide to investment decisions provided that the projected future annual cash savings can be assumed to remain constant.

For example, suppose the installation of a heat recovery device is considered. The heat recovery system installation costs Rs.10,00,000 and will last five years. The law permits a 20% annual linear depreciation factor. The new machine is expected to save Rs.3,00,000 in fuel costs annually.

6.3 Return on Investment (ROI)

The returns may be on the investment made or on a particular project or of the organisation as a whole.

Return on Investment (ROI) : $\text{Profit/Capital Employed}$

ROI is a combination of two ratios i.e., Profitability Ratio and Capital Turnover Ratio

Profitability ratio indicates the profitability of the organisation/investment/project while Capital Turnover Ratio indicates the efficiency with which the assets / investment are being employed. Greater the two ratios, higher will be the return on investment.

Generally the management analyses Profitability Ratios to take decisions pertaining to pricing policies, costs etc., while the Capital Turnover Ratio is analysed to take investment decisions.

The expected Return on Investment is generally the benchmark for investment decisions.

6.4 Pay-Back Period Criterion

The Pay-back Period Criterion evaluates the time required to recover an initial investment via an annual net cash flow. It is defined as the investment cost divided by the cash flow. In the previous example of the heat recovery systems, the pay-back time in years is equal to 3.3 years.

Similar to the return on investment method, the pay-back criterion does not take into consideration the discount rate, the change in energy prices, nor the lifetime of the investment project. It has one advantage over ROI in that a precise indication of the annual benefit, namely the cash flow, is used instead of profits. However, both suffer from the difficulty in justifying the threshold value beyond which no project should be considered.

In practice, investment projects with a pay-back period of three years or less almost always have a positive net present value. Thus the pay-back period is often used as a "filter", calculating NPV when the payback period is over three years and accepting the project when it is less.

6.5 Break-Even Parameters of Net Present Value

An important part of investment analysis, not to be confused with the pay-back period, is the calculation of the threshold value of a critical parameter of the net present value (NPV).

The threshold, or break-even value, is the value of a NPV parameter for NPV equal to zero. Any value beyond the break-even value will cause NPV to become positive and the investment acceptable.

Typical parameters studied in this manner include:

- ◆ The price of the service;
- ◆ The utilisation of the capacity of the investment;
- ◆ Various items of the cost of the project;
- ◆ The energy price increase, and
- ◆ Occasionally, the duration of the project.

When the latter is used as a parameter, the break-even time (in years) is a "true" pay-back period, where the discounted benefits begin to exceed the discounted costs.

Section 7 : Retrofits for Energy Conservation

In this section some of the energy retrofits available in the market are discussed in brief.

7.1 Fuel-Efficient Burners

Commercially fuel-efficient burners are now available in the market which offer a turndown ratio of 7:1 and operate at low excess air levels. They are available in a wide range of sizes varying from 20 l/h to 220 l/h. These burners can handle all types of liquid fuels from kerosene to heavy fuel oils such as furnace oil and LSHS.

Furthermore, these burners are convenient to maintain because it is easy to clean and can be retrofitted immediately, thus reducing the maintenance and shut down time significantly. The burners can be easily replaced without replacing accessories such as the air blower, burner block etc. Energy savings of the order of 10-15% have been reported. The simple payback period is normally less than 6 months.

7.2 Recuperative Burners

The continuous research and development activities in combustion systems have resulted in a new class of energy efficient burners known as recuperative burners. These are specially designed for use in small heat treatment furnaces and multi burner installations where adequate temperature uniformity cannot be achieved by large capacity recuperative or regenerative burners.

These burners are available in three sizes - 45 kW, 75 kW and 150 kW for furnace temperatures up to 1300°C. Each burner is supplied complete with an air driven ejector and individual air-gas ratio control system, which automatically compensates for the variation in air density at different operating temperatures. The performance of a typical 75 kW recuperative burner is given in Table 7.1.

Table 7.1 : Performance of a Typical Recuperative Burner

Furnace Temperature (°C)	Air Preheat Temperature (°C)	% Fuel Savings
800	380	17
900	475	23
1000	550	27
1100	625	33
1200	685	38
1300	740	42
1400	780	45

7.3 Radiant Tube Burners

The heating of furnaces filled with protective atmosphere is accomplished by electric resistors or by radiant tubes, unless the workload lies in a muffle. A radiant tube is a muffle that surrounds the products of combustion. Radiant tube burners are installed when their operation costs less than the use of electric resistors, and the quality of heating is equally good. Generally gas and air are fed to burners in separate pipes. If gas and air are delivered to a burner through pipes, a constant gas to air ratio can be maintained, regardless of turndown, by two interconnected valves that control the total flow of gas and air. The piping arrangement is simplified if gas and air are mixed in correct ratio ahead of the furnace, if they are at atmospheric pressure and if the mixture is delivered to each burner through one single pipe.

7.4 Combustion Control Systems

This is basically to control the fuel-air ratio in a furnace as required by the load and ambient conditions. This maintains high efficiency as the fuel/ air mixture is prevented from becoming too lean, excess air taking too much heat up the' stack, or too rich, resulting in waste of unburnt fuel. The automatic basis of the control system lies in the fact that the fuel and air flows are computed to a balanced state, which readily enables automatic corrections to be made for pressure, temperature and programmed excess air requirements. The system consists of an oxygen sensor system, electronic control system and air flow system. A zirconia cell based probe, which is located in the furnace hot zone forms the oxygen sensor. It is possible to programme the oxygen set point depending on which air flow is controlled to achieve the optimum fuel/air ratio. The system can be fitted on to the existing burner systems without disturbing other process controls.

It eliminates deficiencies of traditional ratio controllers and mechanical linkages by replacing them. It is possible to achieve 5 to 15 % saving of energy depending on the type, size and utilisation of the furnace. The payback period is less than 2 years.

7.5 Recuperators

There are two basic types of recuperator, those that rely on convection heat transfer, and units that transfer heat by radiation. The combination of both types may be used for maximum effectiveness.

a) Convection Recuperators

Convection recuperators can be used where gas approach temperatures are less than 1000°C. Use of metallic recuperators has superseded the earlier ceramic recuperators due to severe leakage problems suffered with the latter. But ceramic recuperators still find application where high pressure/ high temperature are involved. There are two basic types of convection recuperators: those with cast tubes and those using drawn tubes, which are assembled in bundles. The tubes used are available either plain or with a wide variety of extended surface configurations. The use of cast tubes is normally recommended for low pressure applications, where leakage is unlikely to be a severe problem. Drawn steel tube recuperators are often used where it is required to take out considerable portion of the radiation heat, and the tubes are generally not finned. Composite tube recuperators are used exclusively as convection type heat exchangers with waste gas temperatures of up to 950°C. Flue-tube recuperators in which the dirty exhaust gas is passed through the inside of the tubes, while air, to be preheated, is circulated across the tubes, is used where dirty gases are involved, as it is easier to clean the inside of the tubes.

b) Radiation Recuperators

Radiation type recuperator takes the form of two concentric cylinders, the air to be preheated normally flowing through the outer annulus, while exhaust gases flow through the central duct. Alternatively the unit may be built up with tubes between two headers. These recuperators are generally of parallel flow type. Compared with the convection recuperator, the radiation type offers very low resistance to gas flow, and in most instances, never needs cleaning. For this reason even the dirtiest of exhaust gases can be permitted through it. These are used in instances when preheat temperatures in excess of 600°C are required. The radiation recuperator can be regarded as being the most reliable type compared to convection type.

The cost varies depending on the quantity of heat available in the exhaust gas and the type of recuperator used. The payback on investments is less than 3 years.

7.6 Rotating Regenerators

A rotating regenerator, also called Lungstrom heat exchanger, has a wheel which spans two adjacent ducts, one carrying exhaust gas and the other

containing the gas flow which it is required to heat. The gas flows are counter current. As the wheel rotates it absorbs heat from the hot gas passing through it and transfers the heat to the cooler gas flow. The wheel matrix is made of metal or ceramic depending on the temperature application. To minimise leakage and carryover of contamination, it is preferable to operate the exhaust stream at a marginally lower pressure than the supply stream. The contamination of clean supply gas could be minimised by incorporating purging sections on exhaust gas side. These regenerators are generally used in large power plant combustion processes.

7.7 Ceramic fibre insulation

Ceramic fibres are used for any type of hot face insulation in the temperature ranges of 1000 - 1600°C. Commercially produced ceramic fibre essentially consists of alumina (43-95%) and silica (5-57%) with traces of other elements. They are not wetted by molten metals and can be used in direct contact with aluminum, lead, zinc, copper and alloys of these metals. They are resistant to most furnace atmospheres and to oil, steam, water, most acids and many alkalis. The major advantages of ceramic fibres are their low heat transmission, low heat storage, light weight, low thermal expansion, maximum operating temperatures and ease of handling. Commercially they are available in five major forms viz., bulk fibre, blankets, modules, boards and other special forms. The saving in energy varies with furnace type and operation. Typically, for batch operated furnaces the savings can be as high as 30% while for continuously operated furnaces, it is 10-15%. The cost varies depending on the type of fibre and size of furnace. Normally, the payback period is less than 2 years.

7.8 Fluidised Bed Furnace

Fluidisation occurs when a stream of air or gas is passed upward through a bed of finely divided particles. At a certain velocity, the particles separate and float on a cushion of the fluidising air or gas. When the velocity is increased, bubbles form and as they rise through the bed, they cause rapid mixing of the particles in all areas of the bed.

When fluidised, the bed behaves just like a liquid. It is buoyant and light objects float, while heavy objects sink. When heated, the fluidised bed becomes an excellent media for heat transfer.

In the heating context, alumina is used as the fluidising media. Mixtures of air, ammonia, nitrogen, LPG and many other gases are used as fluidising gas as well as the heat treating atmosphere. The gas reactions take place in the bed itself without need for a gas generator.

An alloy retort is used as the container and a special alloy distributor system ensures uniform fluidisation. The bed is heated by gas or electricity externally and in some cases internally. The components are immersed in the bed and lifted out when the treatment cycle is complete, usually with the help of a hoist. Its high heat transfer rate shortens cycle times and packs in more batches per day. Between batches the furnace can be switched off. When this is done, even overnight, the bed retains a major portion of its heat and only needs incremental heating the next day. All these and other features yield an extremely low cost per kilogram processed.

It can be used to carburise, carbonitride, nitride, nitrocarburise, oxynitride and neutral harden, temper, steam blue, black oxide as well as normalise, anneal, marquenched, preheat, age, homogenise, stress-relieve, quench, perform tool steel treatments, thermal shock testing, plastic and paint stripping.

7.9 Ceramic Coating

Ceramic coatings are high emissivity coatings, which when applied have a long life at temperatures up to 1350°C. The coatings fall into two general categories - those used for coating metal substrates, and those used for coating refractory substrates. The coatings are non-toxic, non-flammable and water based. Applied at room temperatures, they are sprayed and air-dried in less than five minutes. The coatings allow the substrate to maintain its designed metallurgical properties and mechanical strength. Installation is quick and can be completed during shut down. Energy savings of 8 to 20% have been reported depending on the type of furnace and operating conditions. The payback period is less than a year.

Appendices

Appendix 1 : Refractory Bricks and their Properties

Any material can be described as a refractory if it can withstand the action of abrasive or corrosive solids, liquids or gases, at high temperatures. The general requirements of a refractory material can be summed up as :

- ◆ Its ability to withstand high temperatures.
- ◆ Its ability to withstand sudden changes of temperatures.
- ◆ Its ability to withstand action of molten metal slag, glass, hot gases etc.,
- ◆ Its ability to withstand load and abrasive forces.
- ◆ Low co-efficient of thermal expansion.

Properties of Refractories

Some of the important properties of refractories are:

- ◆ Melting point : The temperature at which the slag increases in quantity by partial solution of the refractory particles resulting in failure of a test pyramid (cone) to support its own weight is called melting point.
- ◆ Size : It is an important feature in its design.
- ◆ Bulk Density : This defines material present in a given volume.
- ◆ Porosity : The apparent porosity is a measure of the volume of the open pores, into which a liquid can penetrate, as a percentage of the total volume.
- ◆ Cold crushing strength : It reveals little more than the ability to withstand the vigours of transport.
- ◆ Pyrometric Cone equivalent : Temperature at which a refractory will deform under its own weight is known as its softening temperature which is indicated by PCE. The equivalent standard cone which melts to the same extent as the test cone is known as the pyrometric cone equivalent.
- ◆ Refractoriness under load : Gives an indication of the temperature at which the bricks will collapse in service conditions, with similar load.
- ◆ Creep at high temperature : Is a time dependent property which determines the deformation in a given time and at a given temperature by a material under stress.
- ◆ Reversible Thermal Expansion : Is a reflection on the phase transformations that occur during heating and cooling. As a general rule, those with a lower thermal expansion co-efficient are less susceptible to thermal spalling.
- ◆ Thermal Conductivity : Conductivity usually changes with rise in temperature. Low thermal conductivity is desirable for conservation for heat by providing adequate insulation.

Appendix 1 : Refractory Bricks and their Properties

Classification of Refractories :

Refractories can be classified on the basis of chemical composition, use and methods of manufacture :

Classification based on	Examples
<u>Chemical Composition</u> Acidic - which readily combines with bases Basic - which consists mainly of metallic oxides, which resist the action of bases. Neutral - which does not combine either with acids or bases Special	Silica, Semi-silica, Alumino silicate. Magnesite, Chromemagnesite, Dolomite Chrome, Pure Alumina Carbon, Silicon carbide, Zirconia.
<u>End Use</u> <u>Method of Manufacture</u>	Blast Furnace, Casting Pit, etc. Dry Press Process Fused Cast Hand Moulded Formed (Normal, fired or - chemically bonded). Unformed (monolithics-Plastics, Ramming mass, Gunning, Castable, Spraying).

Common Industrial Refractories

Typical refractories in industrial use include:

- a. Fire Clay Refractories
- b. High Alumina Refractories
- c. Silica Refractories
- d. Dolomite Refractories
- e. Magnesite Refractories
- f. Carbon Refractories
- g. Chromite Refractories
- h. Special Refractories
- i. Monolithics

Appendix 1 : Refractory Bricks and their Properties

Fire Clay Refractories

Brick	% SiO₂	% Al₂O₃	% Other Constituents	PCE (°C)
Super Duty	49 - 53	40 - 44	5-7	1745-1760
High Duty	50 - 80	35-40	5-9	1690-1745
Intermediate	60 - 70	26-36	5-9	1640-1680
High Duty (Siliceous)	65 - 80	18-30	3-8	1620-1680
Low Duty	60 - 70	60-70	23-33	1520-1595

They are extensively used for lining iron blast furnaces, hot blast stoves and cupolas. For their marked resistance to thermal fatigue, these refractories are used for regenerative furnaces. Other applications include those in recuperators, annealing, roasting and reheating furnaces, glass melting furnaces. They are also extensively used for flues, chimney linings and in steel casting, pottery, cement, petrochemical and fertiliser industries.

High Alumina Refractories

Typical alumina refractories are composed of bauxite, sillimanite, mullite or corundum base, with the alumina concentration ranging from 45 to 100%. These refractories give better service, due to their good volume stability, high resistance to abrasion and erosion, high resistance to thermal shock and creep. They may be chemically or ceramic bonded. They have found increasing applications in blast furnace stoves and other regenerative furnaces, electric arc furnace roofs, rotary kilns, ladles, cement and lime kilns and glass melting furnaces. Chemically bonded high alumina refractories find special application in alumina melting and holding furnaces for their valuable non-wetting characteristic.

Silica Refractories

Generally , 96-97% SiO₂ with less than 0.3% alkalis are acceptable for silica refractories. However, for super duty silica refractories, the total content of Al₂O₃, TiO₂ and alkalis should not exceed 0.5%. The outstanding property of silica brick is that it does not begin to soften under high loads until its fusion point is approached.

High heat duty silica refractories, with close fitting properties at high temperatures have found application in open hearth furnace roofs besides arches, crowns and other higher parts of various furnaces and kilns. High density silica refractories with large specific surface areas are specially made to suit upper checker work of hot blast stoves used to give higher blast temperatures and where the stove temperatures remain high. They are also used for lining roofs, burner parts of furnaces used in the glass industry.

Dolomite Refractories

Dolomite refractories can withstand temperatures from 1640°C to 2130°C, depending on their composition and structure. They have good resistance to molten steel but have lower resistance to iron oxide and lime slug attacks.

Tar-dolomite mixtures have found extensive use as monolithic linings of L.D and basic Bessemer Converters. Dead burnt dolomite mixed with necessary amounts of tar is used as the ramming mixture for basic open hearth and electric furnaces. Basic open hearth furnace tap holes are closed by dead burnt dolomite alone or mixture of dead burnt dolomite and coke breeze.

Magnesite Refractories

Magnesite refractories find limited applications, due to their comparatively low refractoriness under load, low resistance to thermal fatigue, high thermal conductivity and high cost. They are highly resistive to the corrosive action of basic slag, Open-hearth furnaces, L.D. converters, electric arc and other steel melting furnaces and hot metal mixers are the major consumers of these refractories. Their applications in non-ferrous industries include copper converters and fire refining furnaces, lead, antimony and nickel smelting, refining furnaces, cupro-nickel and other non-ferrous alloy melting furnaces.

Carbon Refractories

Carbon refractories in the shape of blocks, with their marked capacity to withstand heat, load and chemical action during iron manufacture, are increasingly being used for lining blast furnace hearths, bosch walls and cupola hearths. Carbon as a ramming mixture with tar is used for the construction of electrolytic cells.

Chromite Refractories

Chrome magnesite usually contain 15-35% Cr_2O_3 and 42-50% MgO , whereas magnesite chrome refractories contain at least 60% MgO and 8-18% Cr_2O_3 . The former are used for building critical parts of high temperature furnaces, while the latter are suitable at the highest temperatures.

Silicon Carbide Refractories

Silicon Carbide has an important role in ceramic, metal working and process industries because of its excellent combination of properties which include :

1. High refractoriness.
2. Excellent mechanical properties.
3. Good resistance to thermal shock.

Appendix 1 : Refractory Bricks and their Properties

4. High temperature load bearing capacity.
5. High thermal conductivity.

Silicon Carbide refractories are used for metal melting furnaces like Cupolas, aluminum remelting furnaces, crucible furnace linings, crucibles for melting non-ferrous metals, electric resistor bars or spirals in the construction of high temperature furnaces.

Zirconia Refractories

Zirconia refractories have a very high strength at room temperature, which is maintained up to temperatures as high as 1500°C. Thermal conductivity is much lower than that of most other refractories and therefore can be used as a high temperature insulating refractory. It does not react rapidly with liquid metals and is useful for refractory crucibles and other vessels for metallurgical purposes. It is a useful material for glass furnaces, since it is not wetted by molten glasses.

Monolithics

Monolithics are replacing the conventional type fired refractories in many applications, the main advantages being:

- a) It eliminates joints, which is an inherent weakness.
- b) Method of application is faster and skilled measures are not required.
- c) Transportation and handling are simple.
- d) Offers better scope to reduce downtime for repairs.
- e) Offers considerable scope to reduce inventory and eliminate special shapes.
- f) It is a heat saver.
- g) Has better spalling resistance.
- h) Has greater volume stability.

Consumption Norms of Refractories

The consumption norms of refractories in India by the major industries for their operational purposes are given below :

Appendix 1 : Refractory Bricks and their Properties

Consumption Norms of Refractories (kg/t of Product)

Industries	Alumino-Silicate including high alumina and monolithics	Silica	Basic	Insulating	Special Refrac- tories	Total
Iron and Steel	30	2	15.0	0.5	10	57.5
Alloy Steel	30	-	15.0	2.0	25	72.0
Copper	25	-	45.0	0.5	5	75.5
Aluminium	8	-	.01	5.0	18	31.1
Zinc & Lead	5	-	0.2	0.5	1	6.7
Glass	30	8	5.0	1.0	5	49.0
Cement	2	-	0.1	0.1	-	2.2
Ceramics (White ware)	40	-	-	0.5	-	40.5
Refractory	20	3	4.0	-	-	27.0
Power Genr.*	2	-	-	1.0	-	3.0

kg/MWh generated.

Appendix 2 : Insulation

Insulation forms an important area where heat losses can be reduced in order to increase thermal efficiency. Hence, proper selection, application and maintenance of insulating material are critical. The basic function of thermal insulation is to retard the flow of heat energy, either to or from a specific location. Insulation products are specially designed to minimise the three modes of heat transfer viz., conduction, convection and radiation. Insulation materials vary widely in their conducting properties, which is reflected by their thermal conductivity. Thermal conductivity (K) is the amount of heat transferred in unit time through a unit area of unit thickness with unit temperature difference across the face. It is quite obvious that lower the value of 'K', more efficient is the insulation. Table 1 gives the thermal conductivity of various materials.

Table 1 : Thermal Conductivity of Various Materials

	Material	Conductivity kcal/m.h °C
A	<u>Insulating Material</u>	
i.	Magnesia	0.051 - 0.066
ii.	Mineral wool	0.035 - 0.087
iii.	Calcium Silicate	0.049 - 0.079
iv.	Alumino Silicate	0.028 - 0.071
v.	Glass fibre	0.028 - 0.060
B	<u>Resistance film</u>	
i.	Water at 0°C	0.051
ii.	Water at 95°C	0.585
iii.	Air	0.0214
iv.	Scale	0.99 - 2.97
C	<u>Heating Surfaces (Values at 100°C)</u>	
i.	Copper	338
ii.	Aluminium	206
iii.	Cast iron	27.8
iv.	Steel (0.5% C)	44.7
v.	Brass	89.3

The thermal conductivity varies with density, porosity, pore size, in fibrous materials, fibre diameter and shot content i.e., non-fibre particles of rock on glass wool. It also varies with operating temperature, which is shown in Fig. A for three commonly used insulating materials.

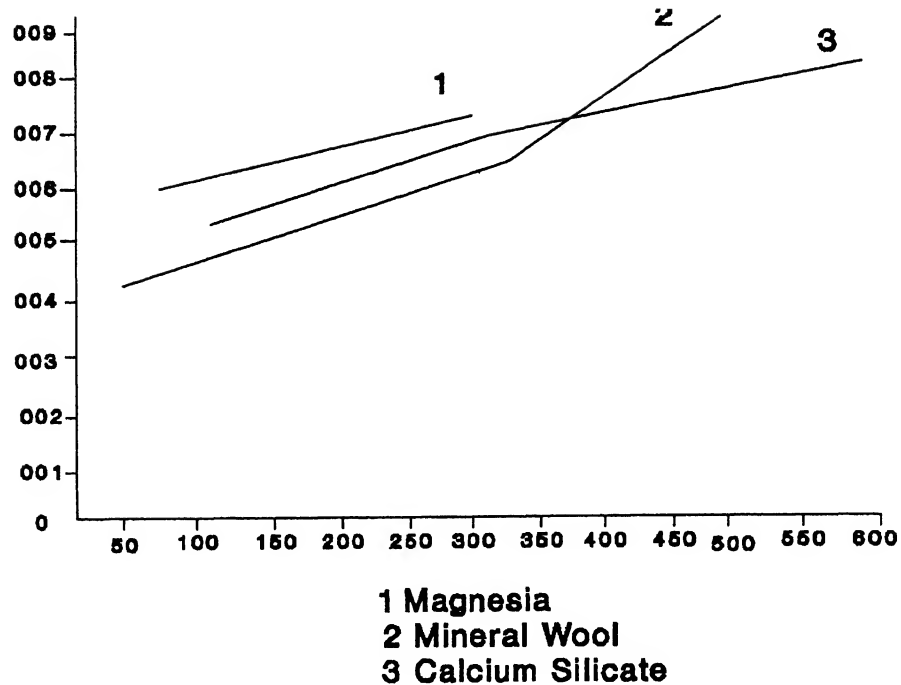


Fig. A : Thermal Conductivity of Common Insulators

Application requirements:

There are three factors that determine the kind of insulation for a particular application:

i) Operating temperature

Reheating furnaces operate at temperatures between 900 and 1300°C. Many types of ceramic fibre are used, with alumina-silica fibres being most common. Insulating fibre bricks, castables and bulk fill materials are used to meet a wide variety of conditions. Again, thermal stability is the controlling factor in determining upper temperature limits of many products used.

ii) Location

For an insulation to remain effective, it must maintain its thickness and thermal conductivity over a period of time. Therefore, the system must either be protected from or be able to withstand the rigors of the environment.

iii) Form required

Obviously, pipe insulation, flat sheets and different forms are manufactured for specific purposes. The various forms available are given in Table 2.

Table 2 : Typical Thermal Insulation Materials and Forms

Insulation	Type	Availability	Density kg/m ³	Temperature limit (app) °C	Thermal conductivity kcal/m. h. °C
Cellular Glass	Cellular	a b	150	450	0.045 at 50°C
Asbestos	Fibrous	e g d	80 - 250	600	0.042 at 40°C
Glass fibre	Fibrous	a d e	10 - 150	550	0.032 at 40°C
Rockwool & Slagwood	Fibrous	a b d e f	20 - 250	850	0.032 at 40°C 0.040 at 110°C
Calcium Silicate	Granular	a b c	200 - 600	850	0.051 at 40°C
Magnesia	Granular	a b c d	200	300	0.05 at 50°C
Diatomaceous	Granular	a b c j	250 - 500	1000	-
Silica	Fibrous	d e	50 - 150	1000	0.033 at 40°C
Alumino Silicate	Fibrous	d e	50 - 250	1200	0.028-0.07 at 40°C
Alumino Silicate	Granular	g f	500 - 800	1200	0.028-0.07 at 40°C
Aluminium	Reflective	h	10 - 30	500	0.026-0.036 at 20°C
Stainless Steel	Reflective	h	300 - 600	800	-
Vermiculite	Granular	c j	50 - 500	1100	0.073 at 40°C

a - slabs,
b - sections,
c - plastic,

d - loose-fill,
e - matters
f - sprayable

g - textiles
j - insulating bricks
h - reflective

Application of Insulation

Since most insulation materials are fibrous and light, they have to be properly supported and applied at the right density, without voids. Therefore, the correct method of application is equally relevant to minimise heat losses. Before application, the surface must be wire-brushed to remove dirt, rust, scale and oil and dried. All surfaces are then brush-coated with a suitable anti-corrosive primer before insulating. The Bureau of Indian Standards gives guidelines on the method of application of insulation. Abstracts from the Code of Practice for the Application and Finishing of Thermal Insulation Materials at Temperatures between 40 and 700°C are given below:

All insulation materials, however fixed, should be applied so as to be in intimate contact with the surface to which they are applied; and the edges, or ends of sections, shall butt up close to one another over their whole surface except in special applications.

While applying multi-layer insulation, all joints shall be staggered; and each layer shall be separately secured to the surface.

The insulation shall be supported when applied to the sides of, or underneath large vessels or ducts or to long runs of vertical piping. Supports are welded either to the hot surface or to bands, which are then strapped round the surface. These supports serve to hold the insulation in place, prevent its slipping or support it above expansion joints. In addition, they provide necessary anchorage for lacing wire or wire netting, which may be required to hold the insulation in place and/or to provide reinforcement for the insulation or a finishing material.

Methods of Application

i) Flexible insulation

Flexible materials such as mats or blankets, faced on one or both sides with a suitable material, are applied by means of tie wire metal bands or wire netting on the outer side and suitably laced.

ii) Rigid insulation

Rigid insulation material such as blocks or boards may be applied by means of suitable metal bands or wire netting on the outer surface.

iii) Thermal insulating cement

Thermal insulating cements are supplied as dry powders, which can be mixed with water to form a soft mortar of even consistency, suitable for application by hand or with a trowel. These cements require heat for drying, to ensure initial adhesion to the surface. All surfaces may be kept warm, throughout the application.

iv) Loose-fill insulation

This is recommended for the following cases.

- a Expansion/contraction joints where rigid insulation has been used
- b Equipment areas where conventional methods may not be feasible.

Appendix 3 : Ceramic Fibre

Ceramic fibre finds a wide range of application in furnaces and contributes significantly towards fuel saving and reduced maintenance cost. It is ideally suited for cyclic operation furnaces, where a major portion of heat from the fuel can be used to heat the stock, not furnace lining. The main characteristics of this fibre are:

- ♦ Light weight
- ♦ Low thermal conductivity
- ♦ Immunity to thermal shock
- ♦ Ease of application, quick installation and repair
- ♦ Resistance to high temperature
- ♦ Not affected by chemicals except hydrofluoric and phosphoric acids
- ♦ Excellent sound absorption
- ♦ Resilience

Ceramic fibre refractory consists of 50 % alumina and 50 % silica. Veneering modules are made of stacked ceramic fibre blanket strips, encased in cotton cloth available in grades of 1260°C and 1425°C. Scrim cloth ensures uniform penetration of the veneering cement. The modules are available in standard sizes of 305 x 1252.5 mm and in thickness of 50 to 75 mm. They are glued onto existing refractory lining to give several benefits. However, refractory surfaces, if old, will require surface preparation before veneering can be done. Table 1 shows the various ceramic fibres available and their properties.

Table 1 : Properties of Ceramic Fibres

Product	Blankets	Modules	Boards/Shapes
Maximum Use/Grade temperature, °C	1. 1425 2. 1300 3. 1260 4. 1000	1. 1450 2. 1325 3. 1300	1. 1600 2. 1425 3. 1260 4. 1260 5. 1260 6. 1000
Dimensions, mm	Width 610, Length - 7620	A. 305 X 305 B. 305 X 305	305 x 610, 457 x 914, 610 x 610, 610 x 914, 914 x 1219, 500 x 1000
Density, kg/m ³	64 , 96, 128 & 160	A:160 B:128 160	1. 512 - 608 2. 320 - 384 3. 640 - 720 4. 416 - 480 5. 320 - 384 6. 272 - 352
Thermal conductivity at mean temperature of 550°C, W/m ² K	0.11 for 128 kg./m ³ 0.13 for 96 kg./m ³	0.12	0.11 to 0.13

Appendix 4 : Fuel Storage and Handling

This is an important and often neglected area, but needs to be given attention in order to prevent wastage or contamination of the primary fuels before use. Fuels, which have been contaminated or degraded by poor storage and handling, are difficult to burn, requiring more excess air, thus lowering thermal efficiency.

Most units use furnace oil for heating, although LDO and HSD are used sometimes. Leakage from pipe joints, flanges, valves and pumps, and spillage because of overfilling are always avoidable. Furnace oil, received by road or tankers, often contains small amounts of dirt, sludge and water, which tend to reduce burner efficiency. Most of these are removed by gravity separation in the main storage tank. Further settling also takes place in the service tank. Foreign matter such as dust, water, coke and sludge particles in fuel oil should be removed by adequate filtration. The properties of important fuel oils are given in Table 1:

Table 1 : Properties of Fuel Oils

Property	LSHS	Furnace oil	LDO
Sulphur content, % wt	1.2	4.0	1.8
Pour point, max., °C	60	27	12-18
Specific Gravity	0.92	0.95	0.86
Calorific value, kcal/kg	10556	10277	10700
Water content, % wt	0.25	0.25	0.25
Ash content	0.1	0.1	0.02

The degree of atomisation of the fuel controls the amount of excess air required to ensure complete combustion. Heavy fuel oils and tars must be heated to reduce the viscosity before atomisation.

Table 2 : Variation of Viscosity of Furnace Oil with Temperature

Temperature, °C	Viscosity, Centistokes
20	50.17
100	5.31
200	1.33
300	0.60

Furnace oil needs to be pumped for transfer. Conservation of pumping energy is possible if the pump head is lowered by a more fluid oil. The oil therefore, needs to be heated to reduce its viscosity. A minimum oil temperature is necessary to maintain the pump head required for transfer of furnace oil. At this raised temperature, all pipes carrying heated oil should be adequately insulated and a minimum of 25-mm thickness of mineral wool tank insulation should be provided. Higher temperatures, due to poor controls, waste more energy than can be recovered in the form of still-reduced pump head. It is usually recommended that furnace oil is heated to about 110°C while LSHS needs preheating only up to 70°C. On the other extreme, diesel needs no preheating.

Clinker

The ash formed by the burning of coal is a complex mixture derived partly from the incombustible mineral matter in the plants from which the coal was formed, partly from the earthy materials with which the plant remains were associated and partly from stony material – for example, so called shale, stone, etc., mined along with the coal. When the coal is burnt, each of these substances contributes its own quota of ash. Any one of these may have a relatively low melting point, but if such easily fusible pieces or particles do melt, adjoining pieces or masses of ash may cement with them to form 'clinker'.

Factors affecting clinker formation

1. The presence of low temperature, fusible, mineral matter in coal.
2. The extent to which mineral matter becomes mixed with fuel in the hottest zone.
3. Coal with wide ash-fusion-range.
4. Coal of high reactivity (generally high rank coal), because it burns at high temperatures, even when the ash fusion properties are moderate.
5. Clinker formation takes time and hence, ash, if allowed to remain long enough in the fire, may form clinker.
6. Manual disturbance of fuel bed resulting in high local temperatures.
7. Once it is formed, clinker has a tendency to proliferate.
8. Clinker will adhere to a hot surface rather than to a relatively cold one and to rough surfaces rather than smooth ones.
9. Small coal, a low ash fusion temperature and a high ash content are a bad combination.
10. Pre-heated air may promote clinker formation by raising the fuel bed temperature.

Methods for reducing clinker formation

The over-heating of a fire bed is one of the main reasons for clinker formation. During periods of normal and heavy load the fire bars are kept reasonably cool by the incoming primary air. When the load is heavy the temperature of the fuel bed rises to a very high level. As soon as the demand falls, the incoming primary air is reduced and the cooling effect decreases. The hot fuel bed raises the temperature of the firebars and similar conditions also occur during banking operations. Air enters to keep the fuel bed hot, but not enough to keep the firebars cool. Under these conditions there is also a risk to clinker formation close to the firebars. The following methods may be adopted to minimise the formation of clinker.

Appendix 5 : Coal Ash Fusibility and Clinker Formation

- A) Water sprays can be applied under the fire grate.
 - 1. To lower the grate temperature
 - 2. To lower the fuel bed temperature
- B) An anti-clinker box can be installed near the refractory wall, because clinker has a tendency to adhere to hot and rough surfaces.

Solid Fuels (Coal)

The combustion of solid fuels normally occurs over grates. The general combustion systems for solid fuel are:

a) Over-feed-stoker

Here, coal is fed by dropping it on to the fuel bed. A moving grate imparts forward motion to the coal bed.

b) Travelling or chain grate stoker

This is an endless metal chain conveyor, which carries fuel in to the furnace and ash out of the furnace. The thickness of the fuel bed and spread of the grate control the coal feed rate. Coal containing a high proportion of fines ($> 30\%$) cannot be burnt, as air passages in the grate are blocked. Coal enters at one end and by the time it reaches the other end, combustion is complete, with ash falling into the ash pit.

c) Under-fired or retort-stoker

Here, fresh fuel is forced into the fire from below, by a screw, and moves out to the sides, as it burns. Burnt fuel and ash automatically move outwards as fresh fuel is forced from below. The advantage is that volatile matter distilled from fresh coal passes through the oxidation zone, ensuring complete combustion.

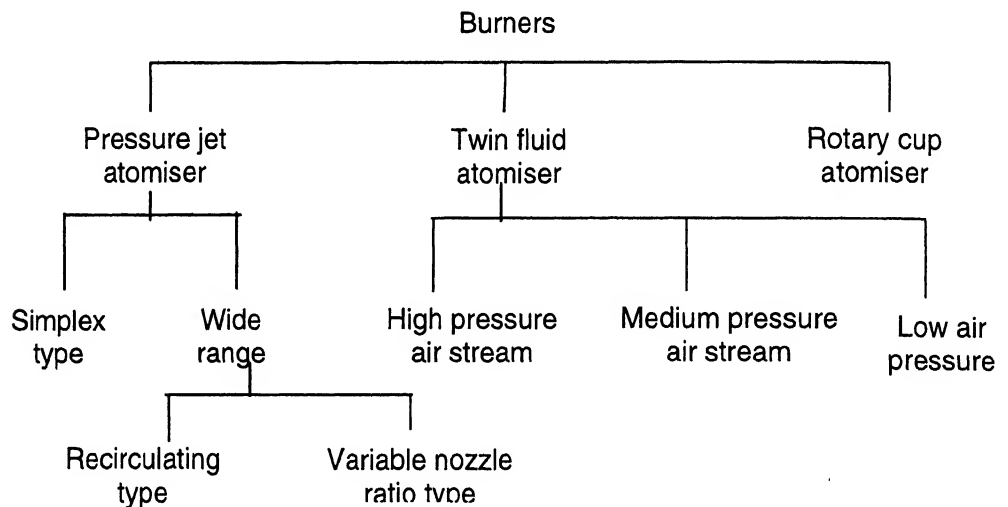
The usual amount of excess air supplied for coal is given below:

Table 1 : Excess Air Supply for Coal

Fuel	Type of Furnace	Excess Air (% by weight)
Coal	Spreader stoker	30 – 60
	Water-cooler vibrating-grate stokers	30 – 60
	Chain-grate and travelling-grate stokers	15 – 50
	Underfeed stoker	20 – 50

Liquid Fuels

The most important component in the combustion of liquid/gaseous fuels is the burner. The main purpose of a burner is to atomise and project the fuel into the combustion chamber. A broad classification of burners, based on the method of atomisation, is given below:



In a twin fluid atomiser, the fuel is injected into the high velocity air stream in one or more discrete jets. In a rotary cup burner, a thin film of oil is formed, by injecting oil into a rapid spinning cup. This film is converted into minute droplets as it leaves the cup, by atomising air fed by the burner.

Pressure jet burners are relatively simpler and inexpensive. However, oil flow rate can be reduced in the simple design, only by reducing oil pressure and hence quality of atomisation. Efficient operation at varying loads usually requires nozzles of various jet sizes.

In medium and high air pressure burners, air for atomising is provided by a compressor at higher pressures. When load changes, the quantity of atomising air is not changed. Only the secondary air entering the system is regulated. Therefore, these burners have better efficiency even at low loads. Compressed air may be replaced by steam as the atomising medium in these burners. Steam aids in cracking of oil in the combustion zone. Steam assisted atomisation is superior for burning heavy fuel oils and LSHS. Medium and high pressure burners should be maintained carefully, since a slight increase in nozzle size can lead to considerable waste of steam or electric power, besides distortion in spray pattern. Atomising air forms a low proportion of total combustion air in these burners. The atomising air velocity is high and combustion

intensity increases proportionately. For these reasons, these burners are more popular for high temperature furnaces, where combustion air has to be preheated.

General Requirement for a Burner/Combustion System

For smooth and efficient combustion, fuel should freely ignite as it enters the burning zone, even with load fluctuations within the specified range. The radiation from flame and hot refractory surface and convection from hot gases should be adequate to ignite fresh fuel. The composition of the fuel-primary air mixture should be within limits of inflammability. To obtain the desired rate of heat release, it is necessary to maintain flame stability throughout the combustion process. Burners should not be operated below or above the stipulated range. The flame should not suddenly come in contact with cold air surface. All factors causing flame extinction or flashback must be avoided. Some flame holders enhance flame stability. High temperature combustion proceeds at a finite rate, hence adequate combustion space should be provided for completion. Otherwise loss of combustibles with exhaust gases will also accentuate smoke. Brown smoke is due to the unburnt combustible vapours. Black smoke is due to carbon black produced by chilling of the flame when it impinges on a cold surface. The flame shape should correspond to the geometry of the furnace and vice-versa.

The quantity of air supply is important to achieve proper combustion. Except a few systems, excess air is always required for complete combustion. The method of air supply should be such that there is an intimate contact between oxygen and the combustibles. This is achieved by creating an intense turbulence in the combustion space. The temperature of combustion gases should be maintained in all parts of the combustion chamber, for smooth ignition, stable combustion and smoke-free performance of the system. Theoretically, the most efficient combustion is that which leads to the highest possible temperature.

Selection of Burner

Burner selection, for a particular operation, depends on five design characteristics. Other factors such as increase of primary air pressure and increase or decrease of fuel pressure have very little influence on these characteristics.

Flame Shape

Design of burner, determining the relative velocities of fuel and air, affects flame length and shape the most. Good mixing, produced by a high degree of turbulence and velocity, produces a short bushy flame. On the other hand, delayed mixing and low velocity result in long lazy flames.

Combustion Volume

The space occupied by the fuel and intermediate products of combustion while burning varies considerably with burner design, pressures and velocities of the fluid streams, fuel and application. Gas burners can be designed to have a heat release as high as 110×10^6 kcal/hr.m² of combustion volume. Light oil burners normally operate at the rate of 270000 kcal/hr.m² and heavy oil burners at 220000 kcal/hr.m².

Stability

This is an important characteristic of a burner, which enables it to maintain ignition under varying conditions of low temperatures, input rates and fuel-air ratios. Improving burner design and providing swirl or jet tubes may enhance stability.

Drive

Drive is the velocity and thrust of the jet stream of hot gases that emanate from a burner. Modern high velocity burners can push hot gases into a loosely piled load with greater velocities than most of the older excess air burners. High velocity burners facilitate re-circulation of gases, improving forced convection. Another advantage of high velocity burners is their ability to reach and wrap around parts of a load that are located away from the burners.

Turndown Ratio

This is the ratio of maximum input rate to minimum. It is the range within which the burner operates satisfactorily. The maximum input rate is limited by a phenomenon called flame blow off, when the mixture velocity exceeds flame velocity. The minimum input rate, on the other hand, is limited by the flashback.

The burner operating parameters are given in the following table :

Appendix 6 : Combustion Equipment

Table 2 : Burner Operating Parameters

Type of Burner	Pressure	Turn-down Ratio	Capacity Gallons/Hr
Low air pressure	Oil pressure 8 - 12 PSIG Air pressure 24" W.G	1.4:1 (without secondary air) 5:1 (with secondary Air)	1/5 - 60
Medium Air pressure	3 to 15 PSIG (Air)	6 : 1	1/2 - 200
High air pressure	Air pressure 15 PSIG Oil pressure higher	Small - 5:1 Large - 10:1	5 to 500
Steam jet	Dry steam 25-175 PSIG Oil pressure	Small - 5:1 Large 10 : 1	5 to 400
Pressure jet	Oil pressure 50 - 200 PSIG	Simplex 2 : 1 Wide range 6.1 to 10.1	Up to 3000
Rotary cup	1/4 to 30 PSIG	4 : 1	3/4 to 250

Concept

Electric arc furnaces are major energy guzzlers in the Secondary Iron & Steel Industry. The furnaces are used for melting of scrap and the recent trend is for melting sponge iron. The specific energy consumption for electric arc furnaces in India is around 650-700 kWh/t of metal melted. This is because these furnaces have not adopted the recent technological upgradations like ultra-high power, eccentric bottom tapping and hot heel practice, oxy-fuel burners, computerised melt controls, foamy slag practice, waste heat recovery etc. Technologies and practices such as these have enabled the world's leading companies to operate their furnaces at a specific consumption of 380-400 kWh/t.

Oxy-fuel burner is one such innovative technology, which has been prevalent in the Iron & Steel Industry. The idea behind this measure is to provide directional input of heat during the meltdown of scrap in the electric arc furnace. The heat is input by supplementing electric power with liquid/gas fuels.

The thermal distribution of heat in any a.c electric arc furnace is non-uniform. This is illustrated in Fig. 1. In an arc furnace, each arc delivers its heat to a section of the furnace in the vicinity of the arc. The three arcs repel each other by electro-magnetic force, thus creating a concentration of arc heat outside each electrode.

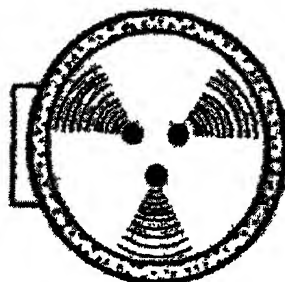


Fig. 1 : Heat Distribution In Ac Arc Furnace

Appendix 7 : Oxy-Fuel Burner

This phenomenon leads to the formation of cold spots in the furnace. The meltdown becomes asymmetrical leading to slowing down of melting process and undesirable occurrences like metal splashing.

Burners are used to provide heat to the local cold spots, usually near the periphery of the bath or near the doors. These burners use liquid fuels or natural gas and oxygen is also delivered through the burner for combustion. Air is not used to prevent ingress of nitrogen and avoid unnecessary exhaust gas losses. Figures 2 & 3 illustrate the use of oxy-fuel burners on the sidewalls of a furnace.

The oxy-fuel burners can be introduced through the slag door or can be fixed to the sidewall or roof margins depending on the size and shape of the furnace and location of cold spots.

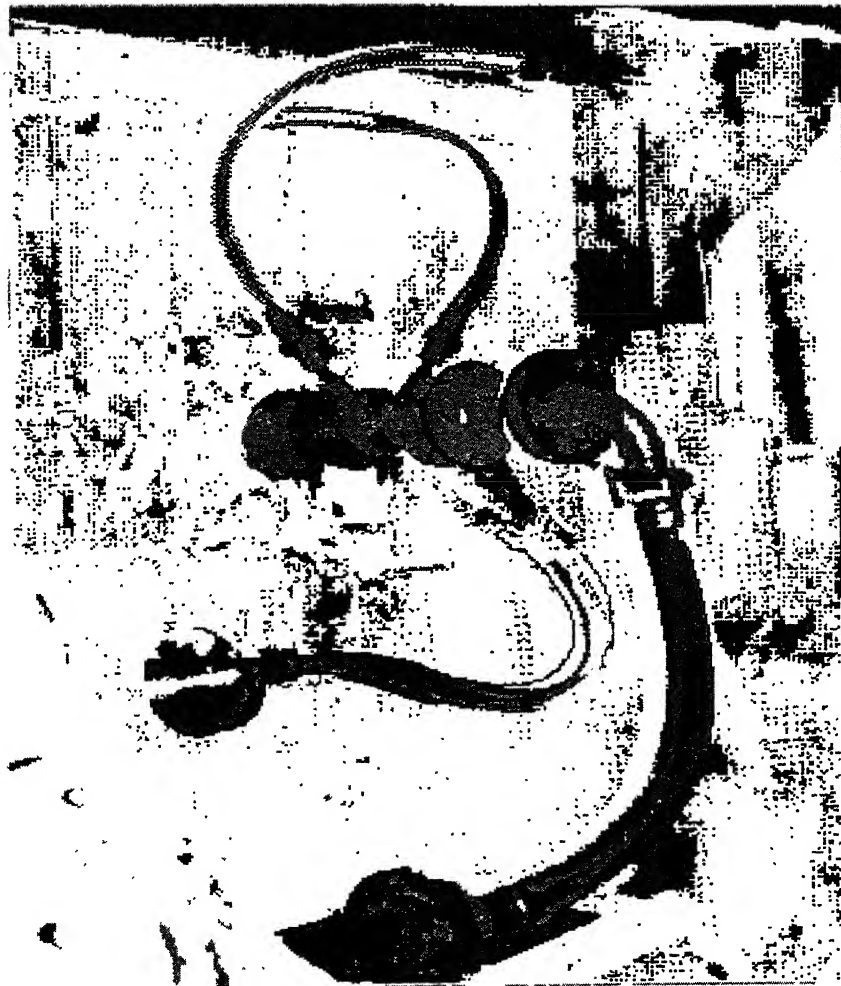


Fig 2 : External View of Oxy-Fuel Burner Installed on Sidewall

The burners provide directional, controlled heat to the cold spots. The melting and heating process in the arc furnace is speeded up and the fixed losses by way of cooling water and surface are reduced. The electric power requirement is thus reduced and replaced on a smaller scale by heat from fuels.

Application Potential

Energy conservation by oxy-fuel burners is applicable to all electric arc furnaces in the secondary Iron & Steel Industry. There are nearly 200 electric arc furnaces in the country and around 40 furnaces are of 20 t and above capacity. It is more beneficial in furnaces where there is single or multiple charging of scrap. A larger size furnace would require 3 fixed oxy-fuel sidewall burners whereas a furnace of 10-15t may make use of an oxy-fuel burner introduced through the slag or side door.

Energy savings of 5-6% of the specific power consumption in electric arc furnaces are being realised by oxy-fuel burners. This technology is not used in any of the furnace units in the country. Thus a good potential for improved energy efficiency through this measure exists in the country.

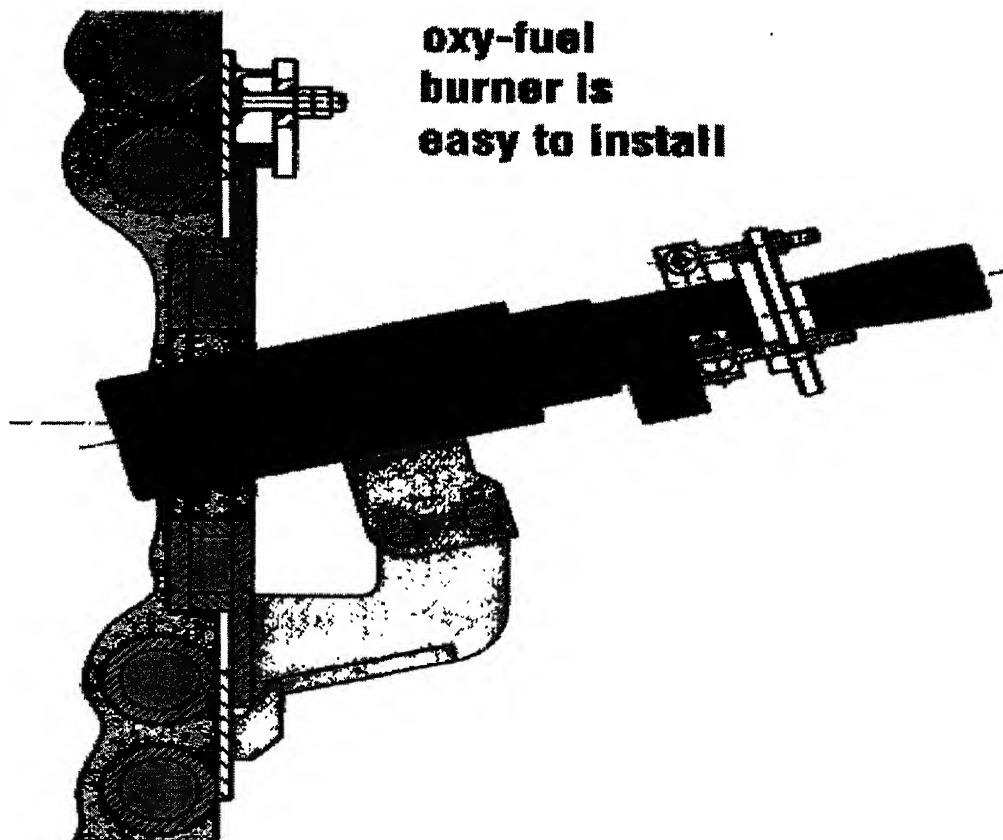


Fig.3 : Diagrammatic Representation of Oxy-Fuel Burner Mounting

Energy Saving Potential

The use of oxy-fuel burners has brought down the specific power consumption by a maximum of 40 kWh/t in electric arc furnaces. In addition to the energy savings, the other benefits are increased productivity and reduction in melting time. There is also a marginal decrease in specific electrode and refractory consumption.

The estimated investment could be Rs. 10-25 lakh, depending on the number of burners, type of fuel, local conditions in a unit etc. The payback period for oxy-fuel burners is 8-12 months even after considering operating cost of fuel and oxygen.

Existing Installations

At present, there are no Indian industries using these burners in the electric arc furnaces. It is reported that the burners have been tried at one or two arc furnaces and the experiment was not successful due to insufficient technological backup.

The arc furnace industry outside India has a large number of installations of oxy-fuel burners and it can be safely stated that it is a very common retrofit.

Appendix 8 : Efficient Ladle Pre-heating System

In any metal melting process it is very essential to maintain the molten metal temperature during pouring, transportation & casting. Ladles are employed to transport the liquid metal to casting facility. To avoid the drop in liquid metal temperature during transport and casting, pre heating of ladles are essential for efficient and safe operation. The other objectives of ladle preheating include avoiding thermal shock due to high temperature difference between ladle refractory & hot molten metal, driving off moisture present in the lining, preventing undue chilling of liquid metal & avoiding skull formation, to prevent solidification of molten metal in side the ladle, etc.

The primary importance of ladle preheating cycle is to supply gradually a quantity of heat to the ladle walls and distribute it uniformly through out the refractory to obtain an adequate temperature gradient to over come the heat losses during transportation and pouring.

An oil-fired burner is commonly used for ladle preheating, where oil is fired in an open atmosphere. The heating station will be either vertical or horizontal. In case of steel melting units ladle refractory lining is normally preheated to the temperature between 700-1000°C and the oil consumption vary in the range 3.5-4.5 liters per Mt.

Though ladle preheating consumes substantial energy, it is often given a lower priority. None of the heating stations use heat recovery techniques and little attention are given to fuel economy.

The study of conventional ladle preheating study reveals the following:

- The efficiency of process given by the heat stored in the refractory varies in the range 25-45%. The energy efficiency of heating a cold ladle is as low as 10%.
- Major losses are flue gas losses, which accounts majority of heat input due to non-existence of waste heat recovery units.

Thus need for energy efficient ladle preheating arises with the following objectives:

- To reduce the energy consumed in preheating
- To reduce the energy consumed in melting units by avoiding the excess superheat of the molten metal
- To increase the lining life of the ladle
- To improve the working conditions in the shop
- To achieve more uniform heating.

Appendix 8 : Efficient Ladle Pre-heating System

A substantial improvement in energy utilization can be made in ladle preheating by simple changes and in-corporation of the waste heat recovery unit.

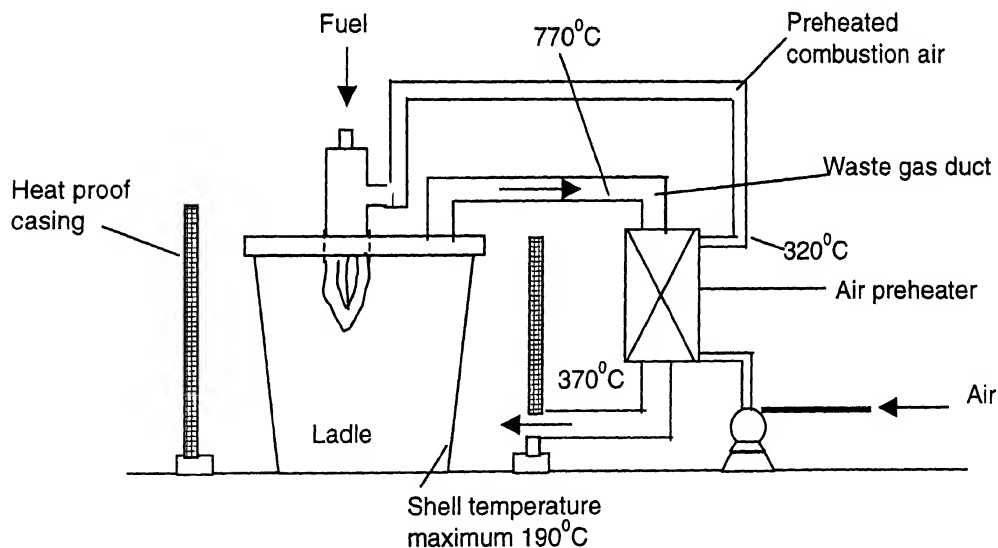
Product Profile:

The energy efficient ladle preheating system incorporates a recuperator in the exhaust gas duct to preheat the combustion air. Furthermore the exhaust gas is used to heat the outer surface of the ladle. The advantages of this system are:

- Combustion air preheat temperatures can reach as high as 320 °C
- The outer surface can be preheated up to 190 °C
- Energy savings in the order of 8-20%
- Uniform distribution of temperature across the refractory
- Reduction in heating cycle

This system of ladle preheating has come into vogue in Germany as a result of search for energy savings. In India, there is no such type of system even though design and development of unit is not complicated. A schematic representation is shown in Fig.

Fig.1 : Schematic Representation of Ladle Pre-heating System



Appendix 8 : Efficient Ladle Pre-heating System

Areas of Application

This system can be applied in Mini steel units (having furnace capacity above 10 Mt.) and using ladles for transport/casting/refining applications.

The installation of such units is simple and doesn't invite any technology transfers, and existing units can be easily replaced. In India, so far no manufacturer developed such packaged units.

Energy Saving Potential

Energy saving potential vary according to the industry and capacity of the ladle. In case of steel industry the energy saving potential is about 8-20%. Estimation of energy saving potential is evaluated by considering a ladle capacity of 50 Mt (Source: Energy audit of a local Iron & Steel Industry conducted by TERI).

Capacity of the ladle	: 50 Mt.
Ladle preheat temperature (hot face)	: 950-1000°C
HSD consumption rate	: 147 kg/h
Flue gas temperature	: 860°C
Proposed temperature of combustion air	: 320°C
Percentage possibility of heat recovery	:30%of heat in flue gases
Percentage savings	: 9% heat input
Savings in fuel	: 90 kL per year
Cost savings	:Rs.5.9 lakh/year
Approximate investment required	: Rs. 6.0 lakh
Payback period	: One year

Preliminary Energy Audit (PEA)

PEA is a preliminary data gathering and analysis effort in two parts: (a) energy management audit, wherein the auditor acquaints himself with investment decisions and criteria referencing energy conservation projects and (b) technical energy audit using available data.

The energy auditor relies on his experience to gather all relevant written, oral or visual information that can lead to a quick analysis of the existing energy situation. It focuses on the identification of obvious sources of possible improvement in energy use, such as missing insulation, steam and compressed air leaks, inoperative instrumentation and superfluous operation. The typical output of a PEA is a set of recommendations for immediate low-cost actions and, usually, a recommendation for a detailed energy audit.

Detailed Energy Audit (DEA)

This is a measured survey followed by a plant energy analysis. Sophisticated instruments, such as flow meters, psychrometers, flue gas analysers and infrared scanners are used to enable the auditor to compute efficiency and balances during typical equipment operation. The tests performed and instruments required depend on the type of facility, the objective, scope and level of handling of the energy management programme. The tests conducted include combustion efficiency tests, measurement of temperature and airflow of major fuel-using equipment, determination of power factor degradation caused by various pieces of electrical equipment and testing of process systems for operation within specification.

After obtaining the results, the auditor validates them using preliminary computation and existing support materials such as tables and charts. Then, he builds energy and mass balances, first for each major piece of equipment tested, and then, for the plant as a whole. From such balances, he can determine the energy efficiency of each equipment and scope for possible improvement in efficiency, with costs and benefits of selected options for each opportunity. In some cases, he is unable to recommend a specific investment because of its magnitude or the associated risk. In such a case, he may recommend specific feasibility studies such as boiler replacement, furnace modification, steam system replacement and process changes. The detailed report presents the auditor's recommendations, with costs, benefits and implementation aspects.

Steps in Energy Audit Programme

In an Energy Audit, detailed data are collected and analysed. Although sophisticated instruments are used, energy auditing is not an exact science. The auditor must use his knowledge and judgement to collect and interpret data suitably. The various steps in an energy audit programme are given below:

Step 1. Review energy management programme to date

The programmes are customarily reviewed with senior corporate staff. The auditor can decide what changes may be needed in the scope of the proposed detailed energy audit. If there is no formal programme, the auditor will try to understand why.

Step 2. Conduct preliminary energy audit

The preliminary energy audit (PEA) should be conducted after the review. The PEA consists essentially of gathering and analysing data. It uses available data only, without the use of sophisticated instruments. The results of the PEA depend on the ability and experience of the auditor. The output of the PEA is normally:

- *Development of energy consumption / cost data base for a facility*
- *Objective evaluation of plant condition*
- *Identification of major energy-consuming systems*
- *Understanding of company policies for energy-related projects*
- *Action plan for future energy auditing work*

The PEA generally has six steps.

- 1. Organise resources**
 - *Manpower / time frame*
 - *Instrumentation*
- 2. Identify data requirements**
 - *Data forms*
- 3. Collect data**
 - a. Conduct informal interviews**
 - *Senior Management*
 - *Energy manager/co-ordinator*

Appendix 9 : Energy Audit Approach and Methodology

- *Plant engineer*
- *Operations and production management and personnel*
- *Administrative personnel*
- *Financial manager*
- b. Conduct plant walkthrough/visual inspection**
 - *Material / energy flow through plant*
 - *Major functional departments*
 - *Any installed instrumentation, including utility meters*
 - *Energy report procedures*
 - *Production and operational reporting procedures*
 - *Conservation opportunities*

4. Analyse data

a. Develop database

- *Historical data for all energy suppliers*
- *Time frame basis*
- *Other related data*
- *Process flow sheets*
- *Energy - consuming equipment inventory*

b. Evaluate data

- *Energy use - consumption, cost, and schedules*
- *Energy consumption indices*
- *Plant operations*
- *Energy saving potential*
- *Plant energy management programme*

5. Develop action plan

- *Conservation opportunities for immediate implementation*
- *Projects for further study*
- *Resources for detailed energy audit*
 - *systems for test*
 - *instrumentation - portable and fixed*
 - *manpower requirements*
 - *time frame*
- *Refinement of corporate energy management programme*

6. Implementation

- *Implement identified low cost/no cost projects*
- *Perform Detailed Audit*

Step 3. Develop action plan, including detailed energy audit

On the basis of the review and the PEA, the energy auditor should develop an action plan, including a Detailed Energy Audit (DEA), considering:

- *Management of energy-related matters*
- *Monitoring and reporting considerations*
- *Relationships with manufacturers' representatives*
- *Availability of resources for implementing the action plan*

Step 4. Select scope of detailed energy audit

The next step is to determine the scope of DEA, in order to finalise resources requirement in the following areas:

- *Manpower: Manpower required for the DEA should be selected, on the basis of the review of the PEA, from internal or external sources.*
- *Instrumentation: The DEA provides the basis for the quantitative analysis of the energy performance of the facility. To compile the operating data necessary to make this quantitative assessment, a variety of fixed and portable instrumentation is used.*
- *Testing procedures: There are standard testing procedures for evaluating equipment performance, which the auditor may use as guidelines. For example, BIS 8753 provides methods for calculating the combustion efficiency.*
- *Cost for conducting the DEA: This depends on the time required to complete the DEA, in other words, the size of the plant and the report preparation time. The use of sophisticated instrumentation and overheads also add on to the cost of the DEA.*

Step 5. Complete preparatory work

All instruments should be calibrated, serviced and/or repaired, additional instruments purchased and test measuring positions and connections completed. The auditor should make sure that the time selected for the audit does not conflict with the operation of the equipment to be tested or the plant in general. The testing date should also be representative of normal plant operation.

Appendix 9 : Energy Audit Approach and Methodology

Step 6. Carry out detailed energy audit field work

The energy auditor can now conduct the fieldwork for the DEA, which comprises two main tasks:

The first task is to gather data to evaluate all energy aspects using the PEA as a starting point, expanding on it, to fill gaps and learn more about the plant operation.

The auditor usually interviews selected personnel, examines records, observes operations, monitors and checks conditions. This may involve repeated data collection and review.

The most important part of an energy audit consists of the preparation of energy and material balances, first for individual equipment operations and then, for the entire plant. Without such data, it is rarely possible to carry out quantitative analyses to identify potential energy savings. Instruments play a vital role in measuring, indicating and controlling process parameters to achieve energy efficiency.

The second task is to perform tests on selected equipment to evaluate its efficiency.

Step 7. Evaluate collected data

Based on the raw data generated, efficiency of various equipment is evaluated. This involves detailed calculation, using computers and at times, specially designed software.

Step 8. Identify conservation opportunities

The results of the evaluation can be used to identify the energy conservation opportunities:

- *Better operation and maintenance by low-cost housekeeping measures*
- *Recovery of waste energy*
- *Improvement in equipment efficiency*
- *Installation of advanced control systems*
- *Change of technology*

Appendix 9 : Energy Audit Approach and Methodology

These low cost opportunities require little or no major capital investment and have immediate returns on investment. On a simple payback basis, they have paybacks of less than a year.

Capital-intensive measures require large investments. Simple payback periods are usually more than a year. The auditor should use payback period as a guideline, while making his list of recommendations. He should also keep in focus, the attitude of the management towards capital-intensive projects.

Step 9. Develop action plan of implementation

The auditor will probably not have the authority to implement the measures identified, especially if capital requirements are large. Instead, he will complete a report, which will present his findings, with a concrete and time-bound action plan.

It should usually be possible to implement some O&M measures immediately. However, capital intensive measures may require feasibility studies before a decision can be made to implement them.

An action plan often includes a recommendation for self-financing. In a self-financing programme, O&M changes are implemented and the resulting cost benefits are invested directly in lower-cost capital-intensive measures to bring in more savings. Eventually, these savings are used to pay for the most capital-intensive measures.

Step 10. Continue to monitor energy use

Energy efficiency in a company cannot begin and end with the DEA. To sustain its energy efficiency, a company must continue to monitor its energy use.

The DEA report should recommend improvements to the existing monitoring and reporting procedures for energy use. Very few companies, if any, have an adequate system of monitoring procedures. Without such a system, it is hard to spot changes in consumption that result from increase or decrease in efficiency. Possible improvements that can be made to monitoring and reporting procedures include:

- *Upgrading of instrumentation*
- *Development of energy consumption indices*

Appendix 9 : Energy Audit Approach and Methodology

➤ Development of energy models

Step 11. Refine overall energy management programme

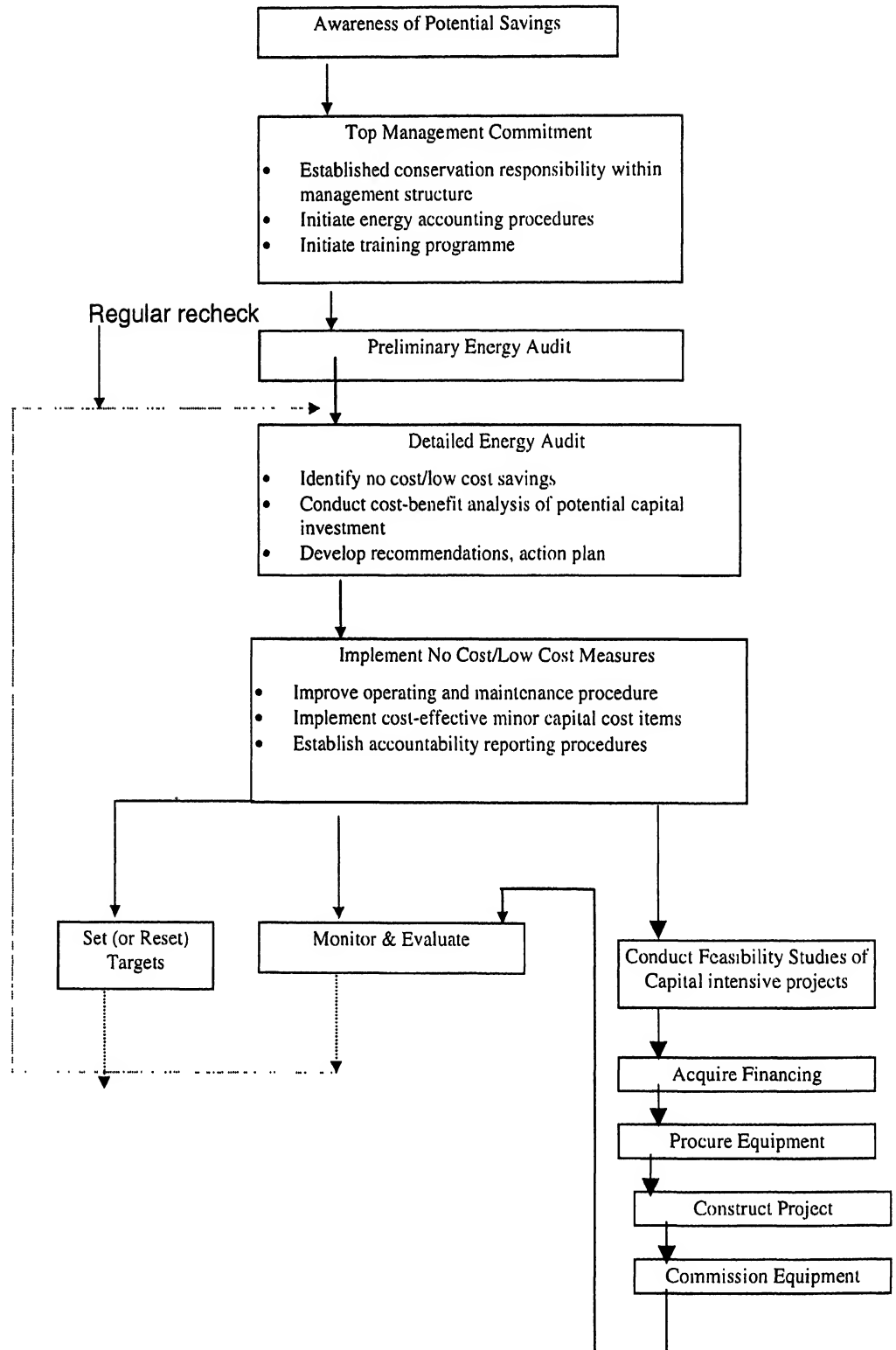
The major recommendations of the DEA should be refinements to the overall corporate energy management programme. Since energy affects so many aspects of operations, improvements in energy use cannot take place without commitment at the highest levels of management and a proper organisational framework. The management's perception of the state of energy use will determine the success of any energy management programme. Recommendations may include:

- Appointing personnel to be responsible for energy***
- Formally structuring a corporate energy management programme***
- Training staff and employees in energy awareness***

In its efforts to maintain energy consumption within levels consistent with technological developments, the management may carry out regular energy audits to review the results of the improvement measures.

Energy Management Practice

The energy management process in totality can be represented as below:



Appendix 9 : Energy Audit Approach and Methodology

The Approach to Energy Management

The commitment of top management should be clearly demonstrated in policies and directives, with company decisions to control costs being clearly defined. Active participation in energy related activities by senior management is a vital step in this approach. Chart A presents this concept schematically. Practising energy management includes mandatory functions such as:

- *Identification of possibilities for further improvement*
- *Evaluation of these opportunities to prioritise them*
- *Implementation of conservation measures*
- *Continuous monitoring to sustain and further improve upon these measures*

Preliminary Analysis

In order to develop an energy management programme, it is necessary that the scope, extent of detail and the management cost and time expended should have some relation to the potential benefits of the programme. The cost incurred should not be more than the value of energy saved. The preliminary analysis should include with a preliminary analysis of parameters such as:

- *Consumption of various forms of energy*
- *Energy cost as percentage of production cost*
- *Major energy intensive equipment*
- *Potential savings and comparison with current profit*
- *Cost of additional metering possibly required to introduce the programme*
- *Efforts within existing framework to monitor energy consumption in different departments.*

Such a broad evaluation would give a perspective of the management time and cost value in relation to potential returns.

Energy Committee

Within the company, and particularly for larger industries, an Energy Committee would play a vital role of co-ordination between various departments. This may, for example, include senior managers, the Accountant and the Chief Engineer. Since accountability and authority go hand in hand, the Chairman should be a senior functionary, with authority to ensure that all resources are made available for necessary actions.

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The Committee will be responsible for:

- *Developing the energy policy*
- *Managing the monitoring system*
- *Concurring upon and reviewing standards and targets*
- *Examining energy saving schemes*
- *Ensuring project implementation*
- *Any other matters relating to energy*

Energy Manager

A full-time energy manager may be appointed to implement the energy management programme, directly accountable to the energy committee. This would also be evidence of the management concern for and commitment to energy conservation. The energy manager should be an internal appointee, to ensure good practical knowledge of all aspects of operations, both technical and administrative.

Responsibility for Results

In general, organisation structures in the industry are based on three levels of authority with corresponding responsibilities towards efficiency of energy use.

Level 1: *Senior Management with responsibility for energy efficiency in the entire organisation, in relation to other resources, and in production of particular products.*

Level 2: *Middle Management with similar responsibilities, but limited to specific areas of the manufacturing process or divisions of the organisation.*

Level 3: *Process Operators, Foremen and Supervisors with responsibility for maintaining efficiency in a particular item of plant or part of a process.*

At all levels, regular reports on actual usage compared against norms and targets will be required in order to learn and correct deviations. The energy manager would provide these reports, analyse data, develop standards of performance and derive information for setting appropriate targets. He would also be responsible for installation and operation of metering systems and the training of staff for the collection and analysis of data.

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Energy Management Process/Strategy

There are four distinct steps to the energy management process:

- *Defining energy accounting centres*
- *Measurement*
- *Analysis & Monitoring*
- *Targeting*

Energy Accounting Centres (EAC)

Along the energy flow paths of the plant, a series of energy accounting centres can provide the breakdown of energy input and output, for monitoring and achieving set targets. An EAC might comprise an individual equipment, a section or even a whole building. Each centre must have an individual responsible for both operational achievement and energy conservation, in order that his attention is focussed on the close relationship between the two aspects. He should have available pertinent information, on which to base judgements, decisions and actions to bring about improvements. Each EAC requires meters to measure the energy consumed over a period, and a means of measuring the production (or other specific variable) over the same period. As far as possible, EACs should correspond with the existing cost control centres.

Measurement

In order to be managed effectively, any resource must be measured accurately, to provide information to base decisions. Energy management depends on collection of relevant data, to judge current performance and plan for future improvements.

Analysis & Monitoring

Energy consumption and cost data can be collected and effectively used to analyse and evaluate performance. This involves regularly comparison of actual levels of consumption with a theoretical consumption defined by a set of internally based standards. These standards could be derived from a knowledge of the organisation's own capability, and then possibly further checked by reference to external norms. Difference between actual consumption and the corresponding standards will reveal either improvements in energy efficiency or a fall-off in performance levels. The information gathered, thus provides quantified evidence of

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the success of implementation, or will indicate any failures, in order that remedial measures can be undertaken.

The analysis should be a continuous process, and each line manager or plant operator must receive the energy throughput data regularly - on a weekly/ monthly basis - and promptly, so that deviations from standards can be quickly detected and corrected. In turn, line managers themselves must ensure that they respond rapidly to the information they receive. Well-designed reporting forms, expressed in readily understood terms, will be very helpful. Management information systems must ensure that the appropriate data and deviations reach the highest levels of authority. Just by the introduction of a monitoring system alone, many organisations have found that they could cut their energy consumption by up to ten percent.

Targeting

Once the energy management programme has identified and prioritised on the implementation of various measures, targets can be set for the implementation of change and the achievement of the predicted energy cost savings. The choice of targets will take account of current standards and the time frame for implementing measures. A organisation may wish to set a range of targets, taking note of the scope for improvement, the resources allowed by management to effect the improvement and the need to match accountability to the energy-accountable centres.

There are two principal methods of target setting. This first is the 'top down' approach, a broad based generalised technique, which does not draw on a detailed analysis of the circumstances of the organisation, but may be based on experience in the sector as a whole.

The second 'bottom up' method is based on a close knowledge of the energy requirements of different parts of an organisation. Both have their merits and can be chosen, depending on the efficacy in the given circumstances. Most organisations prefer the 'bottom up' approach since it is, by its very nature, more closely tailored to there needs and hence more effective.

Correctly set targets have a strong motivational effect on the workforce. But it is important to avoid either impossible or too easy targets, since these can provide counter productive.

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Importance of Human Element

Means of Getting Good Co-operation from Personnel

a. Education

A well-designed familiarisation programme should convince employees of the need for good standards of housekeeping and energy awareness. They should appreciate that it is in their best interests to avoid unnecessary and excessive use of energy. Energy savings add directly to profit. However, it is important to emphasise that sacrifices are not being sought, nor are the employees expected to work in less than satisfactory conditions. Early results are unlikely to be sustained indefinitely. People do tend to slip back into former habits, but the right climate can be established for introducing more complex and lasting measures gradually.

b. Awareness and information sharing

In most plants, employees have little or no idea of the amount of energy consumed within their plant, their section and even the equipment operated by them. In such a situation, what is required is awareness - which can be possible only by information, in the form of comparisons of historical trends, goals for overall energy use, energy intensity, in physical and monetary terms; checklists for each manufacturing operation outlining routine housekeeping measures, audio-visual presentations and literature.

Information must be presented in a manner that facilitates comprehension. If the information is too technical, theoretical, sketchy or dull, it is likely to be ignored or not understood. Terminology should be familiar to the daily life of the employees. For example, a sign saying, " stop steam leaks" will not be as effective as a sign saying " A quarter inch diameter steam leak costs Rs. 30,000/- per month".

Training is also an important means of both informing and involving people at all levels in an energy management programme. For operating personnel, training is required in practicalities of energy saving. This could be integrated into the organisation's other training programmes.

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c. Motivation

Motivation is based on involvement, commitment and a sense of personal accountability. Top management must visibly demonstrate their attitude, originate the programme, generate and maintain the momentum.

Operators and maintenance staff should be involved actively, as they are ultimately responsible for execution. They are often in a better position to recommend areas for improvement. The most effective way of involving them is by simply going out and talking to them regarding goals, achievements, problems and progress or lack of progress.

Supervisors and middle level management should be involved by being assigned responsibilities for implementing and monitoring activities and submitting performance reports to top management, and by getting them to interact and communicate with operators and maintenance stand on progress and problems. If possible, energy management activities should be made a part of each supervisor's performance or job standard.

d. Publicity

Publicity and promotion are essential to publicise the benefits to the company and the workforce. Some commonly used means could be:

1. *Articles or implemented ideas in company or plant paper.*
2. *Obtain local newspaper interest and coverage.*
3. *Posters and pamphlets*
4. *Letterheads with energy conservation messages and ideas*
5. *Plant-wide, high-visibility vehicles or equipment to carry signboards*
6. *Monthly posting of results for the plant and department*
7. *Direct interactions of plant energy manager and personnel.*
8. *Quarterly site reviews and walk-through of unit.*
9. *An agenda item on energy conservation included at staff meetings.*
10. *Material provided to first-line supervisors for employee discussion periods.*
11. *Quarterly meetings held in the plant for all unit representatives*
12. *An Energy Awareness Day is set aside in the plant twice a year*
13. *A Company energy logo developed and adopted.*

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Key Tasks of Energy Management

Energy Data Collection and Analysis

- *Maintain records of all energy consumption in the plant*
- *Check the reading of all meters and sub-meters on a regular basis.*
- *Specify additional meters required to provide additional monitoring capability.*
- *Develop indices for specific energy consumption relative to production and maintain these indices on a monthly basis for all major production areas.*
- *Set performance standards for efficient operation of machinery and facilities.*

Energy Purchasing Supervision

- *Review utility and fuel bills; ensure proper and optimum tariff application*
- *Investigate and recommend fuel-switching opportunities*
- *Develop contingency plans in the event of supply interruptions or shortages.*
- *Work with individual departments to prepare annual energy cost budgets.*

Energy Conservation Project Evaluation

- *Develop ideas, working with in-house staff, vendors and consultants.*
- *Analyse economics to permit management evaluation of projects.*
- *Obtain management commitment of funds to implement projects.*
- *Re-evaluate projects in tune with growth of company*

Energy Project Implementation

- *Initiate equipment maintenance programmes for energy saving*
- *Supervise the implementation of conservation projects, including specification, requests for quotation, evaluation of offers, ordering of materials, construction/installation, training, start-up and final acceptance.*

Communications and Public Relations

- *Prepare reports to management, summarising costs and consumption*
- *Effectively communicate with all production and support departments*
- *Develop an awareness programme to encourage active participation*
- *Develop training programmes to upgrade knowledge and skills*
- *Publicise company commitment to energy conservation*

Checklist for Top Management

- a. Inform line supervisors of:
 - *Economic reasons to conserve energy.*
 - *Responsibility for implementing actions in areas of accountability*

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- b. Establish an energy committee consisting of:
 - Representatives from each department in the plant
 - A co-ordinator appointed by and reporting to management.
- c. Provide committee with guidelines as to what is expected of it:
 - Develop uniform record keeping, reporting and energy accounting.
 - Research and develop ideas on ways to save energy.
 - Communicate these ideas and suggestions.
 - Suggest tough, but achievable, goals for energy saving.
 - Develop ideas for enlisting employee support and participation.
- d. Set goals in energy saving, revising it based on savings potential
- e. Employ external assistance in making recommendations.
- f. Emphasise management's focus on conservation activities.

Duties and Responsibilities of Energy Manager/Co-Ordinator

- *Generate interest in conservation and sustain it with new ideas and activities.*
- *Summarise purchases, stocks and consumption, review and report utilisation.*
- *Focus of departmental records of use, ensuring uniformity and consistency.*
- *Co-ordinate efforts of energy users and set challenging but realistic targets*
- *Advise on techniques and source guidance on specialised subjects.*
- *Identify areas that require detailed study and prioritise them.*
- *Maintain records of all in-depth studies and to review progress.*
- *Provide basic handbook of good energy practice for operations.*
- *Advise purchasing, planning, production and other functions*
- *Ensure that health and safety are not adversely affected.*
- *Liase within industry to exchange ideas, protecting confidential data*
- *Contact research organisations, manufacturers and professional bodies*
- *Remain up-to-date on national energy matters and advise senior management.*

Instrumentation for an Energy Audit

Thermal related measurements:

The most common parameter measured is temperature. All evaluations of the heat contents of a stream or the energy consumption of a process depend on the temperature at each point of the stream or in the process. The instruments commonly used for measuring temperature are:

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- *Mercury/ Bimetallic thermometer*
- *Thermocouple and indicator*
- *Thermograph*
- *Data logger*
- *Pyrometer*
- *Hygrometer*

Mechanical related measurements:

Flow measuring instruments:

- *Vane anemometer*
- *Pitot tube*
- *Air flow meter*
- *Orifice meter*
- *Venturi meter*
- *Ultrasonic flow meter*

Pressure measuring instruments:

Ultrasonic Leak Detectors

Speed measuring instruments:

- *Tachometers (Contact and Non-Contact Type)*
- *Stroboscope*

Steam trap-testing instruments:

- *Industrial stethoscope*
- *Electronic trap tester*

Chemical related measurements

- *Fyrite kit (percentage CO₂/ O₂ in the flue gas)*
- *Oxyliser (% O₂, CO₂, flue gas temperature and combustion efficiency)*
- *Flue gas analyser (%O₂,CO₂,flue gas temperature and combustion efficiency)*
- *Dragger (CO)*

Electrical related measurements:

- *Ammeter and Voltmeter*
- *Power factor meter*
- *Power analyser (A, V, pf, kW, kVA, Hz)*
- *Current recorder*
- *Multi-meter*

Lighting related measurements:

- *Lux meter*